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# ROSE ANTHRACNOSE CAUSED BY SPHACELOMA [1]

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## INTRODUCTION

The results of an investigation of the widespread but comparatively little-known anthracnose of the rose (Rosa) are reported herein, and the literature on the subject is assembled for the first time, so far as the writer knows. The investigation, begun in 1925, embodies a study of the disease mainly as found in the test gardens of the American Rose Society, at Cornell University, Ithaca, N. Y., and in the Van Fleet rose collection at the United States Plant Field Station at Glenn Dale, Md. During August and September, 1930, observations were made on a number of rose plantings in England. There has also been available for study diseased material from rose plantings in Japan, New South Wales, Portugal, and elsewhere, together with that intercepted by Federal plant quarantine inspectors from European importations of rose [3] (*30, 44*) [4] and that found in mycological and phanerogamic herbaria in the United States, England, and Scotland. The intercepted material includes part of a rose bouquet brought to the United States by a passenger on the German dirigible *Graf Zeppelin* on its first trip to this country, in October, 1928 (*30, 31, 34, 43*). (Fig. 1, A.)

## ROSE SPECIES AND VARIETIES AFFECTED

The disease discussed herein affects stems, leaves, and inflorescence of the rose, but in practically all cases it has been reported only on leaves of this plant. Discussing the disease on rose leaves in New South Wales in 1903, Cobb (*10, p. 1064*) stated that "rank growing roses, producing large and succulent leaves, are the worst sufferers" and that "some varieties * * * particularly * * * small-leaved and climbing sorts appear almost never to suffer from the disease."

Among the numerous species affected are: *Rosa acicularis engelmanni* Engel., *R. blanda* L., *R. canina* L., *R. centifolia* L., *R. chinensis*

[1] Received for publication Jan. 20, 1932; issued October, 1932. Many of the data herein presented were included in a thesis submitted to the faculty of the Graduate School of Cornell University, June, 1927, in partial fulfillment of the requirements for the degree of doctor of philosophy.

[2] Thanks are due Prof. L. M. Massey, who first called the writer's attention to the disease under discussion, and Prof. H. M. Fitzpatrick, both of the Department of Plant Pathology, Cornell University, and to Prof. A. J. Eames, of the Department of Botany of the same university, under whose direction the present investigation was carried out. The writer appreciates also the criticism of the manuscript by E. J. Butler and E. W. Mason, both of the Imperial Mycological Institute, Kew, England. Acknowledgment is likewise made of the assistance given by other mycologists, including N. L. Alcock, W. Buddin, R. C. Harris, M. H. Moore, W. C. Moore, J. Ramsbottom, A. Smith, T. A. Sprague, and E. M. Wakefield, of Great Britain; Mathilde Bensaúde, of Portugal; J. G. Churchward, T. H. Harrison, and W. L. Waterhouse, of New South Wales; K. Goto and T. Naito, of Japan; J. B. Marchionatto, of Argentina; and W. H. Burkholder, Charles Chupp, N. A. Cobb, H. S. Dean, B. O. Dodge, C. W. Dodge, E. W. Erlanson, H. D. House, C. E. Kobuski, G. E. Nichols, F. W. Pennell, F. J. Seaver, C. A. Weatherby, Cynthia Westcott, and R. P. White, of the United States.

[3] Unpublished records of the Plant Quarantine and Control Administration.

[4] Reference is made by number (italic) to Literature Cited, p. 335.

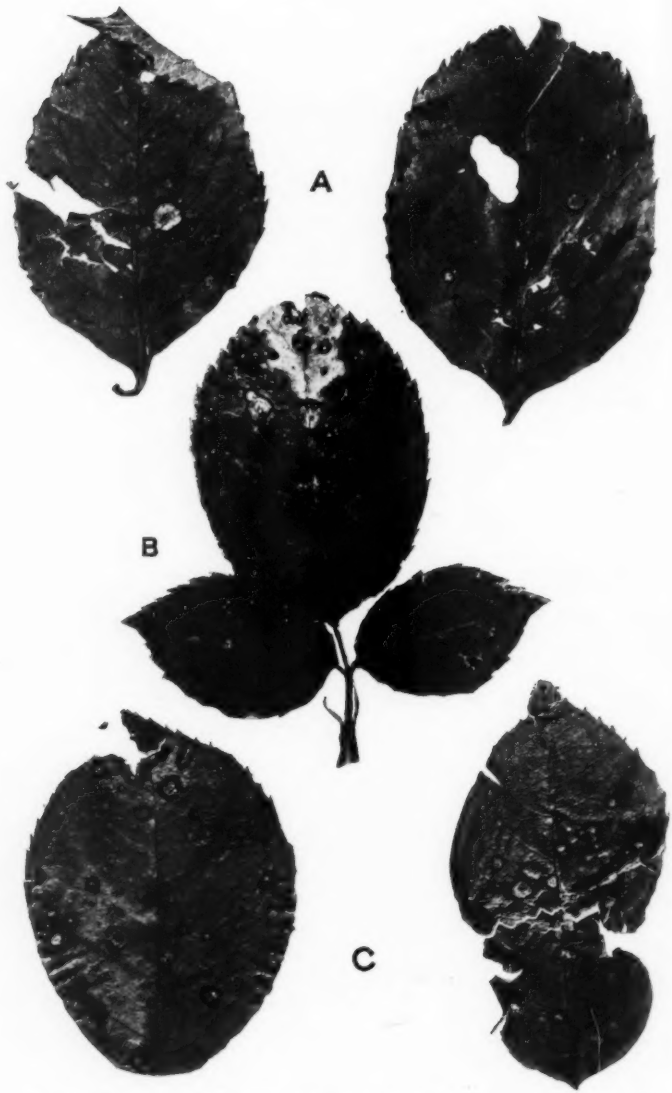
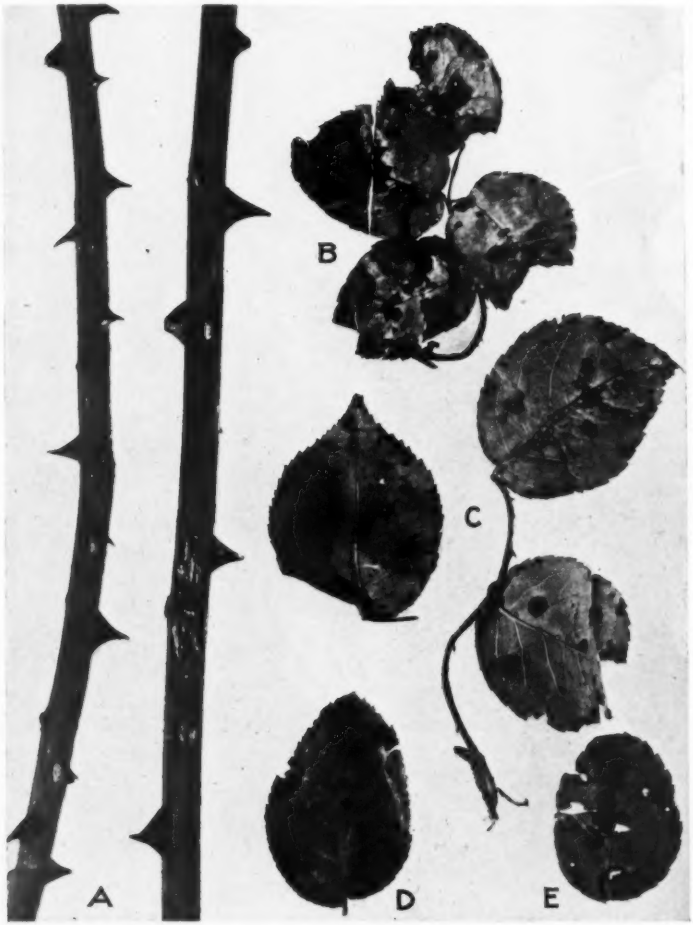



FIGURE 1.—A, Diseased leaves from rose bouquet brought from Germany on the dirigible *Graf Zeppelin* and intercepted by plant-quarantine inspectors at Lakehurst, N. J., October, 1928; B, yellowing in region of anthracnose lesions on leaves of Dora Stober rose from Surrey, England, August, 1930; C, diseased leaves of *Rosa chinensis* sent by K. Goto, from Hiroshima, Japan, December, 1926. × 1. Photographs (A) by M. L. F. Foubert, (B) by J. F. Brewer, and (C) by W. R. Fisher

Diseased leaves and stems of *Rosa gentiliana: a*, Lesion of which lower part has fallen away and remainder has become broken. ×1. From Van Fleet rose collection, United States Plant Field Station, Glen Dale, Md., October, 1926. Photograph by M. L. F. Foubert




Diseased stems and leaves of Dr. W. Van Fleet rose: A, Stems; B, D, and E, upper side of leaves; C, lower side of leaves. × 1. Contributed by Westcott, from test gardens of the American Rose Society, at Ithaca, N. Y., August, 1928. Photographs by M. L. F. Foubert

Jacq., *R. gallica* L., *R. gentiliana* Lév., *R. helenae* Rehder and Wilson, *R. lyoni* Pursh, *R. multiflora* Thunb., *R. nutkana* Presl. (?), *R. nutkana hispida* Fernald, *R. rubiginosa* L., *R. rugosa* Thunb., *R. setigera* Michx., *R. setigera tomentosa* Torr. and Gray, *R. spinosissima* L., *R. sweginzowi* Koehne, *R. wichuraiana* Crép., and *R. woodsi* Lindl. Examples of commercial rose varieties that may be attacked are White Maman Cochet (tea), Dora Stober, Hadley, and Von Scharnhorst (hybrid teas), J. B. Clark (hybrid perpetual), Crimson Globe, Henri Martin (moss), Wartburg (Multiflora), Superba (Setigera), Alida Lovett, Climbing American Beauty, Dorothy Perkins, Dr. W. Van Fleet, Eisenach, Excelsa, Purity, Silver Moon, Sodenia, Valentin Beaulieu (hybrid Wichuraianas), Harison's Yellow (Austrian hybrid), and York and Lancaster (damask). Most or all of the roses here named and many others seem to offer little resistance to infection by the pathogene of the disease. Examples of severely diseased growth of *R. chinensis*, *R. gentiliana*, and *Rosa* sp., var. Dr. W. Van Fleet are shown in Figure 1, B, and Plates 1 and 2, respectively. It is notable that in a large rose garden in England, visited by Westcott and the writer in August, 1930, in no case were the ramblers affected, although the disease was prevalent on near-by bush roses—hybrid teas and probably teas.

## THE DISEASE

### NAME

Cobb (*10, opposite p. 646*), in 1903, published an illustration of a rose leaf affected by the disease discussed herein, labeling it "anthracnose of the rose" (*10, Misc. Pub. 666, p. 96*). In the discussion (*10, p. 1063–1065*), however, the disease was not called "anthracnose" but "blackspot" and was clearly distinguished from the rose disease caused by *Diplocarpon rosae* Wolf, ordinarily referred to as blackspot, but called by Cobb "star-shaped leaf spot." Although Halsted (*15, 16, 17*) had previously assigned the name "rose anthracnose" to a rose disease, this disease, as recently explained (*25*), is apparently of unknown identity. The term as employed by Cobb is here adopted to designate the disease under investigation.

### HISTORY AND RANGE

The known range of rose anthracnose includes most European countries, as well as China, Japan (including Chosen), Australia, Africa, South America, Canada, and the United States. Although occurring in practically every continent of the world, the disease, apparently reported heretofore only on rose leaves, has generally escaped notice or has been confused with other rose diseases, particularly blackspot. It has been observed chiefly on the cultivated rose, but it also affects roses growing wild. The only available record of the disease as observed in China and the earliest records of it as observed in Europe and North America concern its occurrence on wild roses.

Passerini's [5] report of the disease in Italy in 1881, consisting only of a brief characterization of the leaf spot and the fungus associated with it, is the earliest available record of rose anthracnose as a distinct disease. As thus distinguished by Passerini, the disease was later reported in Australia, in New South Wales by Cobb (*10, p.*

[5] PASSERINI, G. ERBARIO CRITTOGAMICO ITALIANO. Ser. 2, No. 1092. Milan, 1881.

*1063–1065*) and in Victoria by Grieve (*14a*); in Japan by Nambū (*35*); in Russia by Iwanoff (*21, p. 100*), Jaczewski (*22, p. 394*), and Siemaszko (*40, p. 32*); and in Germany by Allescher [6] (*2, p. 13*), Diedicke (*12, p. 92–93*), Flachs (*14*), and Pape (*37a*).

As the writer has explained in another paper (*27*), Italian mycologists seem to have diagnosed this rose disease as bramble (Rubus) anthracnose and to have treated these two diseases and others of like nature, including anthracnose of apple (*Malus sylvestris* Mill.) and pear (*Pyrus communis* L.), as one and the same disease. None refer to the report of the disease by Passerini.[7] The three diseases just mentioned, i. e., anthracnose of rose, of bramble, and of apple and pear, are considered by the writer to be distinct diseases, although they resemble one another closely. Some comparisons of their pathogenes are given in a later section.

Additional records of the disease in Europe, in some cases earlier than those already published, are afforded by mycological specimens from Austria, Czechoslovakia, England, and Germany, and by the presence of anthracnose lesions on phanerogamic specimens from France, Germany, Switzerland, Finland, and Scandinavia, as well as by the diagnosis of the disease on roses from Germany (*30*), Spain (*44*), and Ireland,[8] recently intercepted by plant quarantine inspectors.

The oldest mycological specimens at hand showing leaf spot due to rose anthracnose are those from Austria,[9] Czechoslovakia (Bohemia),[10] and Germany.[11] In the first two the leaf lesions were confused with a leaf spot due to Septoria [12] and in the third, apparently, with blackspot.[13]

The phanerogamic specimen from Germany [14] referred to above was collected in the same year as the mycological specimen. The phanerogamic specimens from France, seen in the herbarium of the Royal Botanic Gardens, Kew, England, are of particular interest, as they constitute the earliest known record of the disease. They bear no date but were identified by F. W. Wallroth in 1828 as varieties of "*Rosa scandens*," i. e., "*d. arvensis B. ovata*" and "*d. leucochrea.*" In 1902 Briosi (*7, p. 313*) reported a rose disease from Meaux, France, that is probably rose anthracnose. The disease was observed on garden roses in other parts of France by Burkholder in 1927, and by White and by Dodge in 1930. Dodge states that roses at the National Horticultural School at Versailles were severely diseased. Burkholder in 1930 also observed the disease in Geneva, Switzerland. The occurrence of the disease in Portugal is established by specimens of rose leaves from Portalegre, showing typical anthracnose lesions, recently received through the courtesy of Mathilde Bensaúde.

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[6] Oberammergau, Germany, September, 1901, A. Allescher. SYDOW, H. MYCOTHECA GERMANICA. Fasc. 1, No. 36 (*42, p. 519*). In the mycological collections of the Bureau of Plant Industry as *Phyllosticta rosarum* Pass.

[7] Op. cit. (See footnote 5.)

[8] Op. cit. (See footnote 3.)

[9] Austria, summer, 1871, F. de Thümen. THÜMEN, F. DE. FUNGI AUSTRIACI. No. 590, Century 6, Dresden, 1872. In the Mycological Collections of the Bureau of Plant Industry as *Septoria rosae* Desm. f. *rosaccaninae* Thuem.

[10] Teplitz, Bohemia, autumn, 1873, de Thümen. THÜMEN, F. DE. FUNGI AUSTRIACI. No. 1193, Century 12, Dresden, 1874. In Mycological Collections, Division of Mycology and Disease Survey, Bureau of Plant Industry, U. S. Department of Agriculture, as *Ascochyta rosarum* Lib. f. *centifoliae* Thuem. *Ascochyta rosarum* Lib. = (?) *Septoria rosae* Desm. (*38, v. 3, p. 485*).

[11] Wiesbaden, Germany, Sept. 1873, P. Magnus. Identified as *Asteroma rosae* Lib. (= *Actinonema rosae* (Lib.) Fr. (*38, v. 3, p. 408*)). Ex herbarium, Charles Peck, Albany State Museum, Albany, N. Y.

[12] Op. cit. (See footnotes 9 and 10.)

[13] Op. cit. (See footnote 11.)

[14] *Rosa acicularis* Lindl. Münden, Hanover, May 28; July 14, 1873. H. Zabel, 53. In herbarium, Arnold Arboretum, Harvard University, Jamaica Plain, Mass.

Anthracnose lesions are present on a number of phanerogamic specimens of rose from China preserved in the United States and in England; as, for example, on *Rosa brunoni* Lindl. collected by E. H. Wilson, in 1918,[15] and on a specimen of *R. acicularis* Lindl.[16] that he collected in Chosen.

As already stated, rose anthracnose was observed in August, 1930, by Westcott and by the writer in a large rose garden in England. It was also found at Harpenden by Westcott and in a number of other rose plantings in England by the writer. So far as could be learned, the disease had not previously been recognized there as rose anthracnose. Two specimens from that country, however, preserved in the herbarium at Kew, were diagnosed by Wakefield as affected by bramble anthracnose. One of these, dated October, 1926, was from Suffolk County, the other, dated a month later, was from Reading, having been collected there by Buddin, who sent it to Wakefield. At the department of botany, British Museum (Natural History), London, the writer saw one other specimen of anthracnosed rose leaves from England. These had been collected by Ramsbottom at Littlehampton, in 1928. The disease had not been definitely determined, although Ramsbottom had distinguished it from blackspot due to *Diplocarpon rosae*, as others in England had called it.

Relative to the occurrence of rose anthracnose in Africa, Ramsbottom has told the writer that when he was in that country recently he saw roses unmistakably affected by this disease at Cape Town, Union of South Africa; Bulawayo, Southern Rhodesia; and Nairobi, Kenya. The occurrence of the disease in South America was ascertained through Argentine specimens recently sent by Marchionatto. These specimens also served to verify the writer's assumption that the disease which Marchionatto (*33, p. 11–13*) had earlier reported as possibly Halsted's rose anthracnose is Cobb's rose anthracnose.

The occurrence of rose anthracnose in Canada is established by the presence of lesions on phanerogamic specimens of *Rosa lucida* Ehrh.[17] and *R. humilis* Marsh.[18] from New Brunswick and Quebec, respectively.

In the United States, rose anthracnose is known to occur in Maine, Massachusetts, Connecticut, New York, New Jersey, Pennsylvania, Maryland, Virginia, North Carolina, Florida, Michigan, Texas, and Oregon. Doubtless it is still more widely distributed. In none of the few mycological herbarium specimens available from this country is the leaf spot recognized as that of rose anthracnose. The earliest of these, hitherto undetermined, is from Florida, dated 1893.[19] Other, and in most cases earlier, records are afforded by phanerogamic specimens on which are lesions of the disease. The earliest is dated

[15] Western Szechwan, 1908, E. H. Wilson, 1125. In herbarium, Arnold Arboretum, Harvard University, Jamaica Plain, Mass.

[16] Korea (now Chosen), August, 1917, E. H. Wilson, 8920. In herbarium, Arnold Arboretum, Harvard University, Jamaica Plain, Mass.

[17] Campobello Island, July, 1886, Harry Edwards. In herbarium, New York Botanic Garden, New York.

[18] East Cape, Coffin Island, Aug. 17, 1912, M. L. Fernald, Bayard Long, Harold St. John. No. 7671, FLORA OF THE MAGDALENA ISLANDS, QUEBEC. In Gray herbarium and herbarium of Arnold Arboretum, Harvard University, Cambridge and Jamaica Plain, Mass.

[19] *Rosa* sp. (cult.), Lake City, Fla., November, 1893, P. H. Rolfs. Ex herbarium, Florida Agricultural College, Gainesville, Fla.

1869.[20] In 1918 Massey observed the disease on the Dr. W. Van Fleet rose in the test gardens of the Arlington Experiment Farm at Rosslyn, Va., and on this and other roses in the test gardens of the American Rose Society, at Ithaca, N. Y. He diagnosed the disease as bramble anthracnose.

## ECONOMIC IMPORTANCE

Although rose anthracnose has been observed chiefly on cultivated roses, little information is available concerning its economic importance. This is due partly to its having been confused with other rose diseases. The writer has not made an extensive survey of rose nurseries in this country to determine whether or not the disease is present in them. It was not found in the eastern nurseries visited in the autumn of 1931. However, in the collection of wild roses in the botanical gardens and arboretum of the University of Michigan, at Ann Arbor, it is considered of such importance that measures have been taken for its control. As observed by Westcott and the writer in the test gardens at Ithaca, N. Y., the disease has not been prevalent during the early part of the growing season, but by late summer it has been present on many varieties, both bedding roses and climbers. Anthracnose lesions were usually found to occur on phanerogamic specimens showing fruit and not on those showing blooms.

Cobb (*10, p. 1063*) states that "the disease appears at all seasons" in "the greater part of New South Wales." He recently told the writer that it was serious when he was there in 1903, and specimens from Churchward and from Waterhouse, sent at the request of Harrison, show evidence of somewhat the same condition there at present. Nambū (*35*) states that in Japan the disease may be so severe as to kill the plants, and Marchionatto (*33, p. 13*) reports that in Argentina it is a veritable enemy of the rose. It is said that the lower leaves on the plant are more severely affected than the upper (*10, p. 1064; 35*) and that diseased leaves become yellowed (*10, p. 1063; 33, p. 12*) as well as spotted and may fall away prematurely (*33, p. 12*). Similar injury ascribed by Heald and Wolf (*18, p. 88*) to Cercospora leaf spot may indicate the presence of rose anthracnose; certainly, lesions of this disease occur on rose leaves [21] which those investigators diagnosed as affected by the Cercospora disease.

## SYMPTOMS

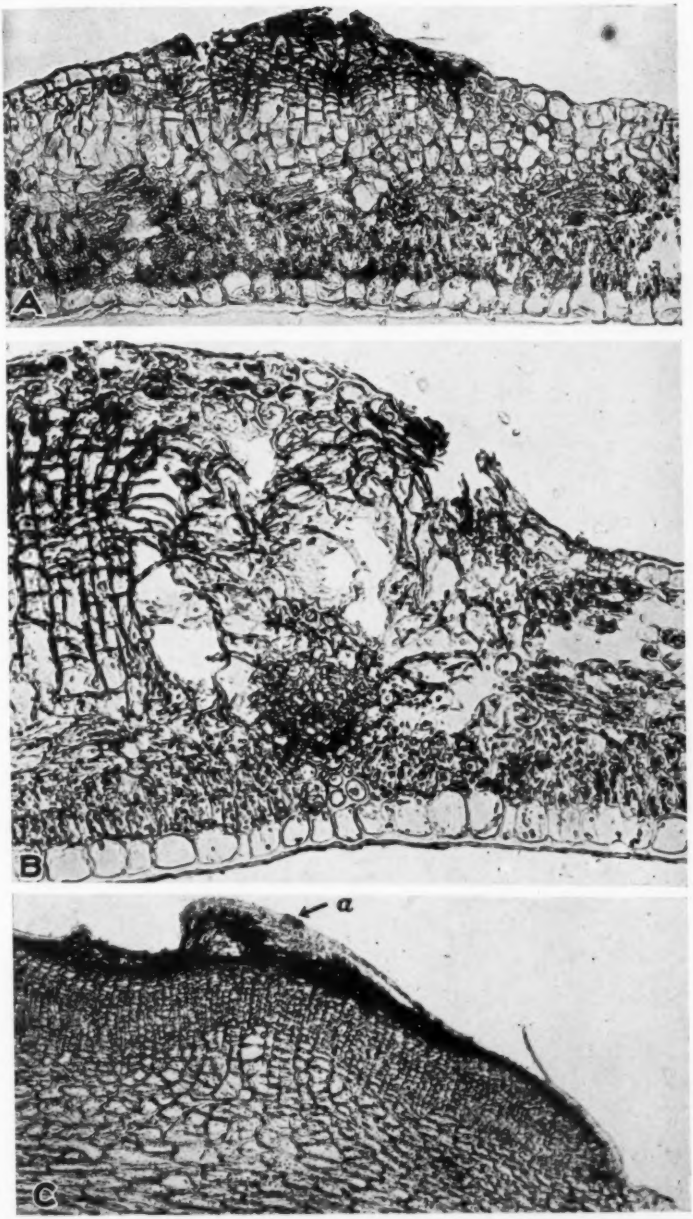
### Leaf Spot

In describing the leaf spot, Cobb (*10, p. 1063–1064*) states that this—

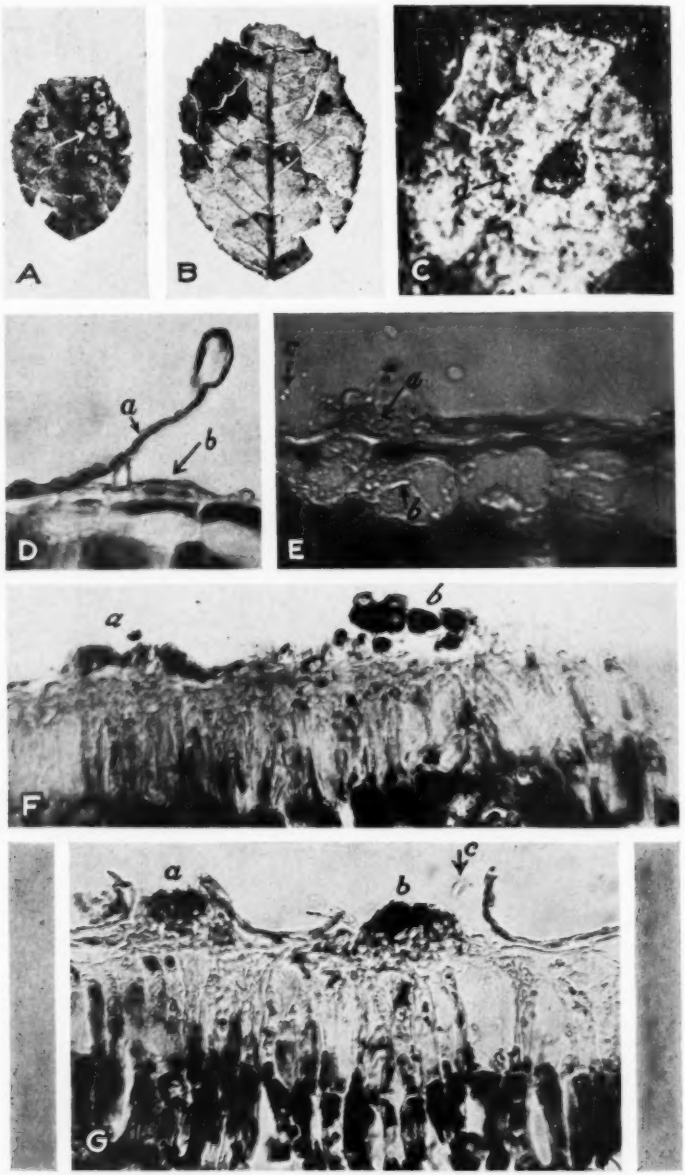
> is characterized by the appearance on the leaflets of dark spots varying in size but seldom more than a quarter of an inch across, except by the amalgamation of several that have originated near each other. The normal form of the spots is circular, and the first indication of their presence is the loss of the normal green color of the leaflet at the place where the future "Black Spot" will appear.

[20] *Rosa carolina* L., Bethlehem, Pa., June, 1869, A. F. Krout. In herbarium, Philadelphia Botanical Club, Philadelphia Academy of Natural Sciences, Philadelphia, Pa.
*Rosa virginiana* Mill. (originally identified as *R. carolina*), Sandy Hook, N. J., October, 1897, Alex. MacElwee. In herbarium, Philadelphia Botanical Club, Philadelphia Academy of Natural Sciences, Philadelphia, Pa.
*Rosa canina*, Jamaica Plain, Mass., Aug. 17, 1888. Ex herbarium, C. and E. Faxon. In Gray herbarium, Harvard University, Cambridge, Mass.
*Rosa nutkana*? Astoria, Oreg., Aug. 31, 1898, F. V. Coville, 839. In U. S. National Herbarium, Washington, D. C.

[21] Brenham, Tex., June, 1909, F. D. Heald and F. A. Wolf, 1456 (*18, p. 88*). In Mycological Collections, Division of Mycology and Disease Survey, Bureau of Plant Industry, U. S. Department of Agriculture.




Sections through anthracnose lesions: A and B, On leaf of Dr. W. Van Fleet rose; C, on stem of *Rosa rubiginosa;* C, *a*, acervulus. A, × 140; B, × 230; C, × 60. Material from test gardens of the American Rose Society, at Ithaca, N. Y., sent by Westcott, August, 1928. Photomicrographs by M. L. F. Foubert




Anthracnose lesions on leaf of Crimson Globe rose: A, Upper side; B, lower side (× about 1½); C, enlargement of lesion at A, *a* (× 22); C, *a*, mass of Coniothecium-like conidia presumably of the pathogene; D–G, sections of A, *a* (× 380); D, *a*, ruptured cuticle; D, *b*, and E, *a*, subcuticular hyphae; E, *b*, intraepidermal hypha; E, *c*, spherical bodies from epidermal cells, interpreted as possibly conidia or storage material, or both; F, *b*, Coniothecium-like conidia, apparently of the pathogene; F, *a*, and G, *a* and *b*, acervuli; G, *c*, conidium, out of focus. Material sent by Chupp from test gardens of the American Rose Society, at Ithaca, N. Y., autumn, 1925. Photographs by J. F. Brewer

* * * From this small beginning the spot increases in size until it reaches the dimensions described above, changing colour meanwhile through dark brown or purple to almost black. Not infrequently a single leaflet bears a score of these spots * * *. At last these spots turn white or at least ash coloured, at the centre, and this is an indication that the fungus which is causing the disease is about to fructify * * *.

Descriptions of the leaf spot by other investigators (*22, p. 394; 33, p. 12; 35*) agree in all essential particulars with that of Cobb. Marchionatto (*33, p. 12*) also mentions the yellowing of affected leaves. This discoloration may consist of a mixture of red and yellow, or it may be red shading later to brown, a rather common symptom of the disease. (Fig. 1, B.) The following additional observations of leaf lesions have been made by the writer:

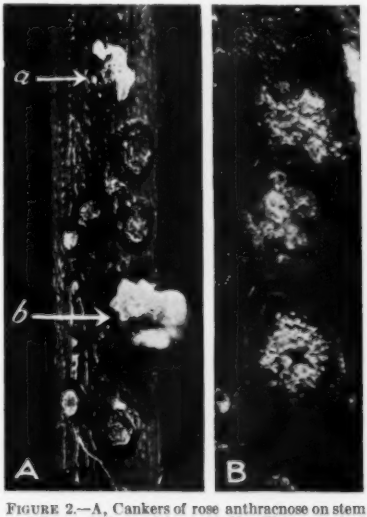



FIGURE 2.—A, Cankers of rose anthracnose on stem of *Rosa rubiginosa*, Ithaca, N. Y. This stem had been disinfected in mercuric chloride(1:1,000), rinsed in sterile water, and kept for 18 days on the surface of a test-tube slant of agar medium, during which period yellowish-green colonies of the pathogene (*a* and *b*) developed from two of the lesions, one colony (*b*) having reached the agar surface. B, Growth of the pathogene from young anthracnose spots on leaf from *Graf Zeppelin* specimen, kept for 5 days in a moist chamber. All × 5. Photographs by M. L. F. Foubert

Lesions may occur on any part of the leaf, including midrib and veins (fig. 1; pls. 1 and 2, B–E) and may be thickened as in the closely related disease known as scab of citrus (*8, 11*) (pl. 3, A and B). They are usually visible on both leaf surfaces. (Pl. 4, A and B.) Lesions are often "dark purplish black" [22] above and are sometimes bordered by a narrow band of "dull livid brown," which is often their color below. Their white or ashen coloration results from a lifting of the cuticle (pl. 4, D, *a*) or from the etiolation of the leaf tissue (pl. 4, F and G) on the surface where the fungus first gained entrance, usually the upper surface. Lesions may fall away beneath, leaving only a thin papery membrane that ruptures easily (pl. 1, *a*); they may become perforated at the center (pl. 4, C); or they may fall out entirely, producing the appearance of shot holes. In addition, affected leaves may become distorted and ragged at the margins. (Fig. 1, C, and pl. 2, B.)

### Stem Canker

Stem lesions or cankers (pls. 2, A, and 3, C, and fig 2, A) are considerably smaller than the leaf spot. They are generally circular, or elongate with the longer diameter parallel with the stem axis. Usually they are raised, and sometimes depressed at the center. (Fig. 2, A.) Often they are "dull livid brown," becoming white or ashen at the center. They are seldom more than 2 millimeters across, although by confluence they may be larger and also noticeably

[22] Names of colors in quotation marks are according to the following authority: RIDGWAY, R. COLOR STANDARDS AND COLOR NOMENCLATURE. 43 p., illus. Washington, D. C. 1912.

irregular in outline. In general aspect, cankers of this disease, which affects thorns as well as other parts of the cane, are suggestive of initial-infection lesions of brown canker (*23, 24*), although they do not enlarge later into more or less extensive cankers as do initial-infection lesions of brown canker. Some roses highly susceptible to infection by the pathogene of the former disease, however, are affected little or not at all by the pathogene of the latter. Examples are *Rosa rugosa*, *R. wichuraiana*, and the hybrid Wichuraianas, Dr. W. Van Fleet and Silver Moon.

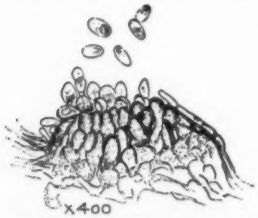



**Fig. 111.**—Spores of *Phyllosticta Rosarum* Pass., the cause of the Black Spot of the Rose. The simple, smooth, colourless, ellipsoidal spores, measuring 5·-7·2 x 2·2-3·2μ, and averaging 5·5-2·6μ, are borne in minute black, nearly spherical perithecia, about 100μ in diameter, which are partly buried in the epidermis of the dead tissue of rose leaves in the midst of more or less circular spots found on the upper surface of the attacked leaves, and characterised by a distinctly concentric arrangement of a striking series of colours, namely, an ash-coloured or nearly white centre, surrounded by brown, purple, and black.

**Fig. 112.**—Spores of the Black Spot of the Rose, *Phyllosticta rosarum*, obtained from the surface of the leaves, and mounted in water and drawn at once. It will be noted that these spores are smaller than those produced in a water-culture shown in Fig. 111.

FIGURE 3.—Drawings of *Phyllosticta rosarum*, with accompanying legends, as published by Cobb (*10*) in 1903

### LESIONS ON BLOSSOMS

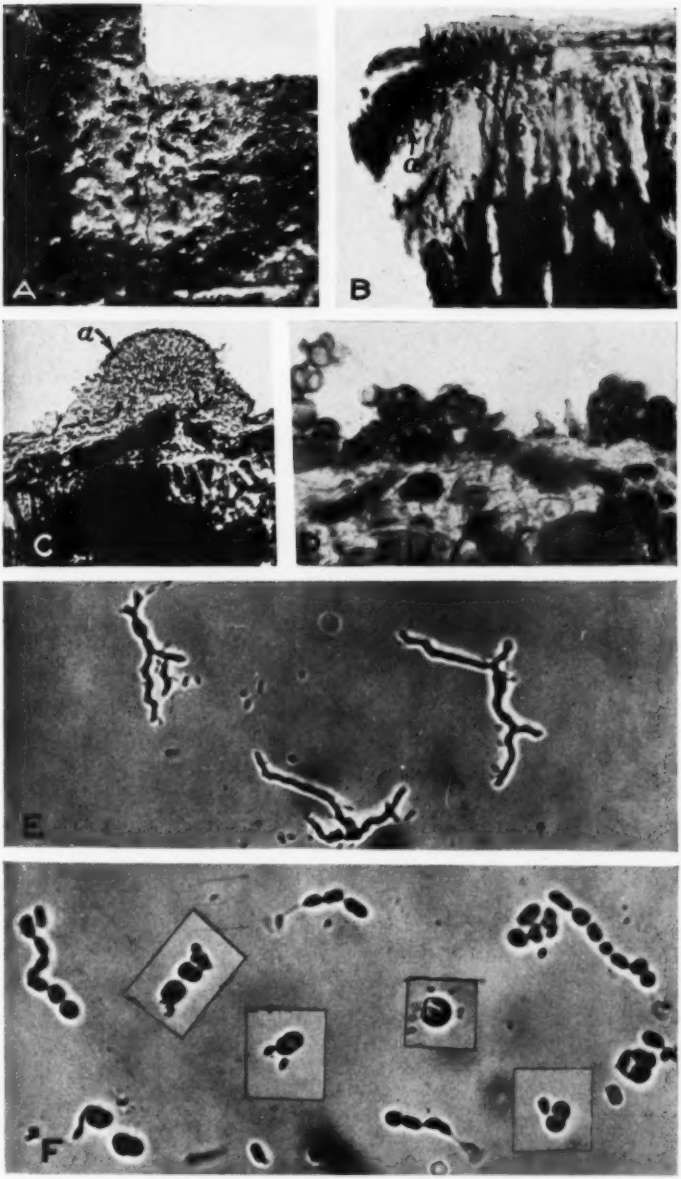
Lesions on the inflorescence observed on hips and pedicels resemble stem lesions; those on calyx lobes, leaf lesions. Petals are probably affected, but lesions on them have not been definitely diagnosed.

## THE FUNGUS

### MORPHOLOGY

The perfect stage of the pathogene of rose anthracnose has not been reported. Passerini [23] gives only a brief description of the imperfect stage. In sending leaves of *Rosa chinensis* affected by anthracnose to this country in 1926 (pl. 2, A), K. Goto wrote that the light yellowish-brown acervuli of the pathogene measured from 28μ to 130μ in diameter; the conidiophores, 7.7μ to 14μ by 2.3μ to 3μ; and the conidia, 5.9μ to 7.4μ by 2.8μ to 5.5μ. For corresponding structures essentially the same measurements were made by Passerini.[23] Cobb (*10, legend for Figure 111*, here reproduced in Figure 3), Marchionatto (*33, p. 13*) and Nambū (*35*) seem to have followed Passerini [23] in applying to the acervulus of the fungus the term "perithecium," signifying pycnidium. It should also be noted here that Saccardo (*39, p. 388*) referred to the acervulus in this fungus as a young pycnidium. He did this in citing Lindau's (*32, p. 352*) reproduction of what is Figure C of Von Tubeuf's drawing as published by Allescher (*2, p. 13, 84*) (fig. 4); he did not cite the illustrations by Cobb herein mentioned and, in part, reproduced in Figure 3. So far as the writer has been able to determine, the fructification referred to above is an acervulus typical of the form genus Sphaceloma (*3*), which through its further development may become a sporodochium. (Pl. 5, C.) Acervuli may be scarcely visible even when examined under a hand lens (see

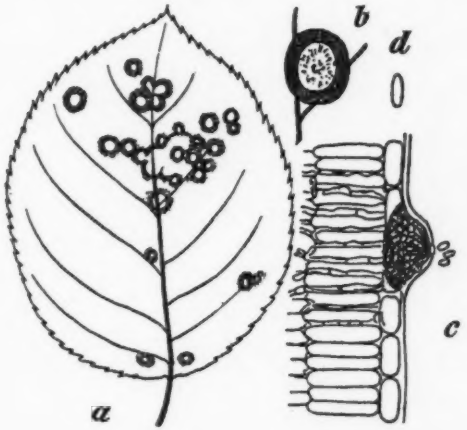
[23] Op. cit. (See footnote 5.)




Pathogene of rose anthracnose. A, Prominent acervuli on leaf lesion from specimen collected at Orono, Me., October, 1900, by P. Spaulding (herbarium of P. Spaulding, No. 209). × 22. B, Section of A, *a*, acervulus; *b*, conidiophores still confined to epidermal cells in which they grew. × 380. C, Section of a leaf lesion shown in Figure 3, A; *a*, sporodochial growth of the fungus; *b*, hyphae passing from lower part of sporodochium, between and beneath epidermal cells. × 200. D, Section corresponding to Plate 4, F, showing additional Coniothecium-like conidia, presumably of the rose-anthracnose fungus. × 380. E and F, 7-day-old water cultures from conidia sown in drops of water on glass slides, kept at room temperature and now germinated (E) or in a refrigerator and now greatly swollen (F). × 380. Photographs by M. L. F. Foubert

pl. 4, C), but they may be fairly prominent (pl. 5, A, and fig. 5) and somewhat concentrically arranged (fig. 5).

Plates 4 and 5 show on rose leaves subcuticular (pl. 4, D, *b*, and E, *a*) and intraepidermal hyaline hyphae (pl. 4, E, *b*), colored acervuli (pl. 4, F, *a*, and G, *a* and *b*, and pl. 5, B, *a* and *b*), and Coniothecium-like conidia presumed to be those of the pathogene (pl. 4, F, *b*, and pl. 5, D), as well as spherical granules (pl. 4, E, *c*) interpreted as possibly conidia or storage substances, or both, produced in the epidermal cells shown in Plate 4, E. There are also shown germinated (pl. 5, E) and greatly swollen (pl. 5, F) conidia producing sprout conidia. These represent 7-day-old water cultures kept at room temperature




**Phyllosticta Rosarum Passer. *a*. Ein Blättchen mit dem Pilze in natürlicher Grösse. *b*. Ein einzelner Flecken etwas vergrössert. *c*. Ein Fruchtgehäuse noch von der Epidermis bedeckt, von der Seite, mit einigen ausgetretenen Sporen. *d*. Eine einzelne sehr vergrösserte Spore. *b* u. *c* stark, *d* noch mehr vergrössert. Nach der Natur von Dr. v. Tubeuf gezeichnet.**

FIGURE 4.—Von Tubeuf's drawings of *Phyllosticta rosarum*, with accompanying legend, as published by Allescher (*2, p. 15, 84*) in 1898

(pl. 5, E) and in a refrigerator (pl. 5, F). The germinated and greatly swollen conidia are those originally sown in these cultures.

## NAME, CLASSIFICATION, AND IDENTITY

Passerini [24] described as *Phyllosticta rosarum* the pathogene of the disease to which Cobb later applied the term "rose anthracnose." Passerini's description of the fungus was based on leaves of the cultivated rose collected at Vigheffio, near Parma, Italy.[24] The writer has seen these specimens at the laboratories of cryptogamic botany, Harvard University, Cambridge, Mass.; the New York Botanic Garden, New York, N. Y. (fig. 6); the department of botany, British Museum (Natural History), London, England; and the botanical

[24] Op. cit. (See footnote 5.)

department, University of Edinburgh, Edinburgh, Scotland. In all cases the leaf spot is typical of rose anthracnose. A fragment of the specimen at the New York Botanic Garden, obtained for microscopic comparison, showed fruiting bodies identical with those here illustrated.

As previously stated, the pathogene of this disease has not only been identified as *Phyllosticta rosarum* but has also been treated (*27*) as identical with *Elsinoe veneta* (Speg.) Jenkins, which causes bramble anthracnose, and with *E. piri* (Wor.) Jenkins, which causes apple and pear anthracnose. For the present, however, these three organisms

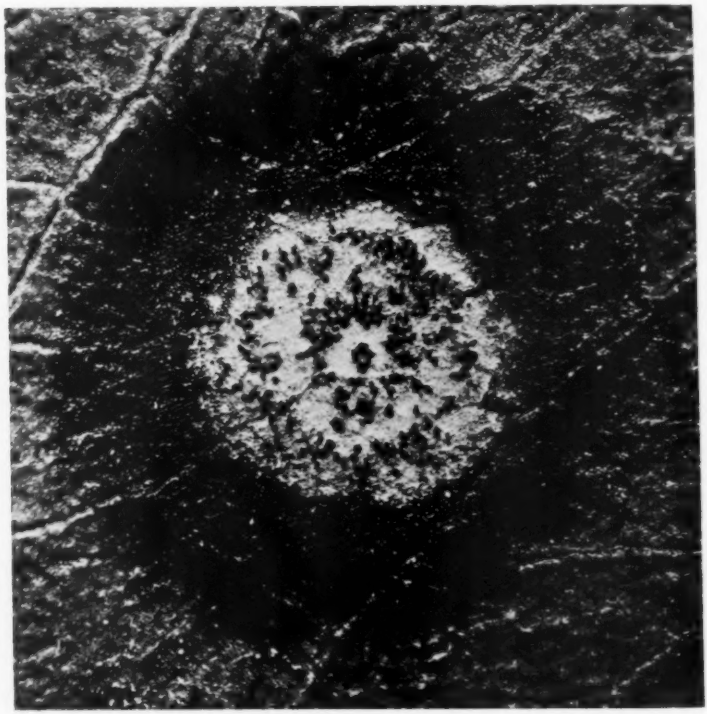


FIGURE 5.—Pathogene of rose anthracnose. Acervuli in more or less concentric arrangement on upper surface of lesion on Silver Moon rose. From test gardens of the American Rose Society, at Ithaca, N. Y., August, 1931. × about 20. Photograph by M. L. F. Foubert

are treated as distinct, as are the three anthracnose diseases that they cause. Since no perfect stage of the rose fungus has yet been found and since its imperfect stage as known is typical of Sphaceloma rather than of Phyllosticta, the fungus is here transferred to the former genus as *Sphaceloma rosarum* (Pass.), n. comb.

In several monographic treatments of the genus Phyllosticta (*2; 32; 38, v. 10, p. 100–138*) the species under discussion is included, and in one (*2, p. 84*) it is employed to illustrate the characteristics of that genus. Moreover *Phyllosticta rosarum*, i. e., *Sphaceloma rosarum*,

has been treated as identical with *Phyllosticta rosae* Desm. (*29, p. 416*) by Von Höhnel (*19, p. 135–136*), but this is evidently another fungus. Von Höhnel (*19, p. 136*) has also expressed the opinion that Passerini's type material, referred to in the previous section, is actually *Phragmidium subcorticinum* (Schrank) Wint. This is not surprising, since

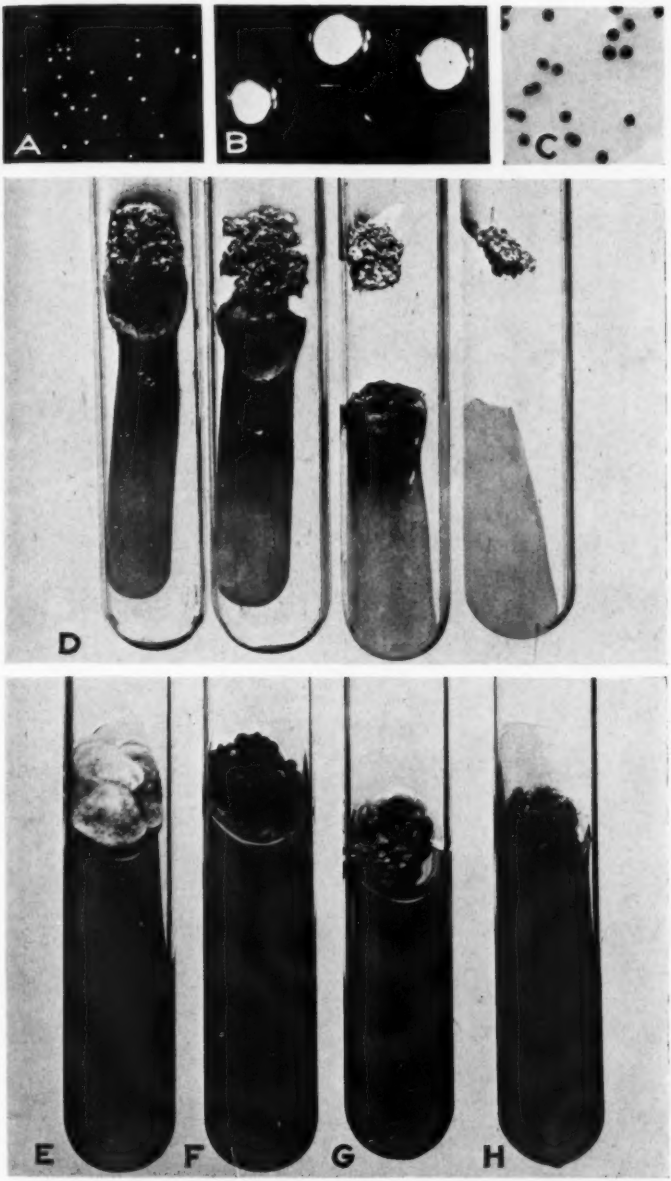
FIGURE 6.—*Phyllosticta rosarum* on leaves of cultivated rose collected by Passerini at Vigheffio, Italy. (PASSERINI, G. ERBARIO CRITTOGAMICO ITALIANO, Ser. 2, No. 1092. Milan, 1881.) Ex herbarium, New York Botanic Garden. A and B, Upper leaf surface; C, lower leaf surface. × 1. Photograph contributed by F. J. Seaver

purple leaf lesions due to rose rust may resemble closely those of rose anthracnose, although the readily recognized rust pustules serve to distinguish the two diseases. Ciferri's (*9, p. 40*) report of *Phyllosticta rosarum* on rose apparently relates to some other rose fungus. *Sphaceloma rosarum* has been confused with still other rose fungi, including *Diplocarpon rosae*, as already mentioned.

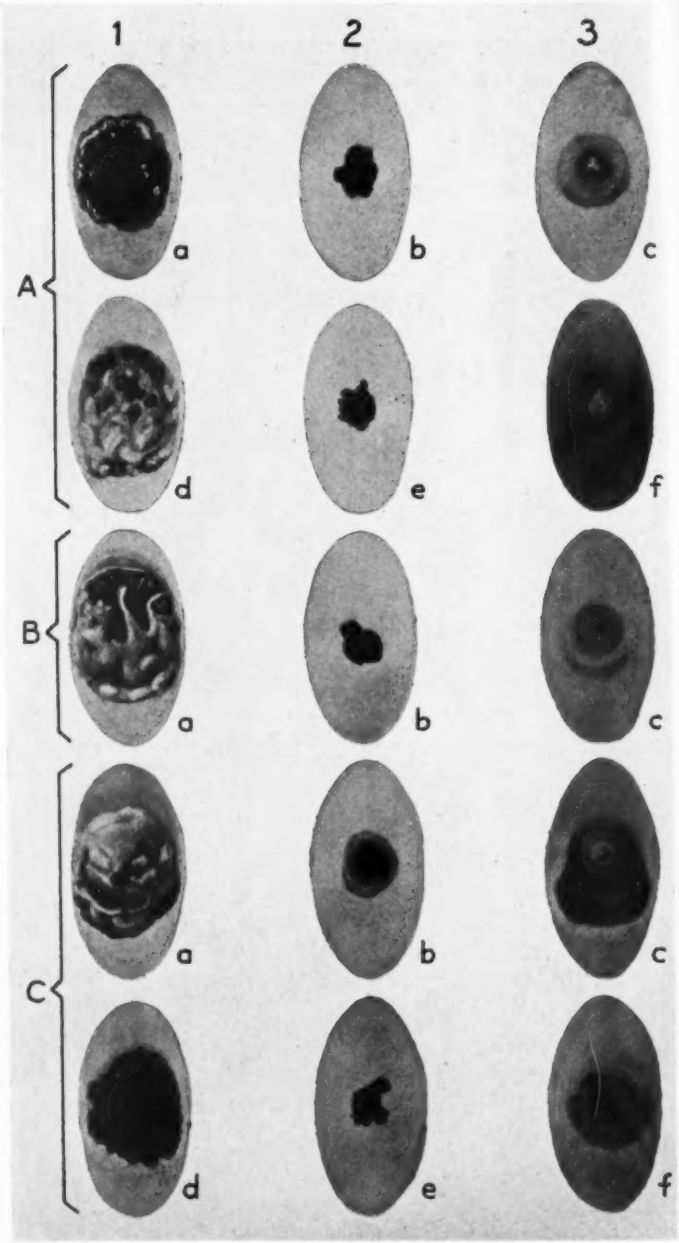
ISOLATIONS AND CULTURAL CHARACTERISTICS

Cultures of *Sphaceloma rosarum* on potato-dextrose agar (pl. 6, A–C) represent platings from conidia developed on the *Graf Zeppelin* specimen. (Fig. 2, B.) The week-old colonies (pl. 6, A and B) were grown at room temperature, and the 3-weeks-old colonies (C) were grown in a refrigerator. The younger colonies were just becoming reddish; the older, viewed through the reverse of the Petri dish, were "liver brown," verging on "black." Individual colonies from the week-old cultures were transferred to test-tube slants of potato-dextrose agar, one colony to each test tube. At 4 weeks of age these cultures resembled that shown in Plate 6, H, which represents a subculture from this set of cultures. Their coloration was then a mixture of "gray" to "dull purplish black" at the center, bordered by "maroon," with the surrounding medium "light vinaceous cinnamon." Typical cultures selected after four months are shown in Plate 6, D. They were then "fuscous black" mingled with "olivaceous black" with the deep crevices and bordering parts, as well as the surrounding medium, "bone-brown." The 5-weeks-old parallel cultures shown in Plate 6, E–H, represent the following isolations: H, a subculture from the set of cultures shown in Plate 6, D; F, a subculture from one of the colonies shown in Figure 2, A; E, an isolation from the Dr. W. Van Fleet rose, made in 1923 by Massey (*28, footnote 2*); and G, an isolation from the same variety made in 1928 by the writer. The culture shown in Plate 6, E, represents the pulvinate type of growth in this fungus and the cultures shown at D and at F to H, represent the convolute type. The occurrence of these types of growth in the genus Sphaceloma has been discussed in a previous paper (*26*), with the explanation that they have been observed in cultures on carrot, Molisch's, and potato-dextrose-agar media.

Cultures of *Sphaceloma rosarum*, *Elsinoe piri*, and *E. veneta* grown under similar conditions are shown in Plate 7. Vertical columns 1, 2, and 3 represent, respectively, potato-dextrose, beef, and corn-meal agar media. These cultures were grown at room temperature and for the most part in the dark. Plate 7 shows the pulvinate type of growth in *S. rosarum* (A, *d–f*), in *E. piri* (B, *a–c*), and in *E. veneta* (C, *a–c*). The convolute type in *E. piri* is not included in this comparison, but, allowing for slight differences, would resemble that of *S. rosarum* (A, *a–c*) and *E. veneta* (C, *d–f*). It will be observed that on the three media here represented any one isolation is distinguishable from the others and that those of the same type of growth resemble each other closely. In other sets of parallel cultures the isolations have varied somewhat in appearance from those here shown, but in each set the individual isolations have been separable; and thus far, whether convolute or pulvinate, each has maintained its characteristic type of growth. On potato-dextrose agar the convolute cultures were much darker and of a more uniform color, in general "dull purplish black," than the pulvinate cultures, which were variegated and lighter in tone. The cultures on beef agar were of a brownish coloration except that shown in A, *e*, which was noticeably lighter than the others. The yellowish-green chromogenesis reported by Osterwalder (*36*) in *E. piri* had been seen in this species as grown, for example, on corn-meal, glycerin, and potato-dextrose agar media. The same chromogenesis occurs in the isolation from




*Sphaceloma rosarum* on potato-dextrose-agar medium. A–C, Petri-dish cultures from conidia: A, week-old colonies grown at room temperature; B, enlargement of a few colonies in A, to show mucilaginous covering; C, 3-weeks-old colonies grown in a refrigerator. D, 4-months-old test-tube slant cultures, each inoculated with a colony from culture shown in A. E–H, 5-weeks-old cultures, each representing a different isolation; E, pulvinate type of growth; D, F–H, convolute type of growth. A–D, Growth from conidia from *Graf Zeppelin* specimen (fig. 3, B); E and G, isolations from Dr. W. Van Fleet rose, made in 1923 by Massey (E) and in 1928 by the writer (G); F and H, subcultures from isolations shown in Figure 3, A, and Plate 6, D, respectively. Photographs by M. L. F. Foubert




Parallel cultures of *Sphaceloma rosarum* (A, *a–f*), *Elsinoe piri* (B, *a–c*), and *E. veneta* (C, *a–f*) on test-tube slants of potato-dextrose (vertical column 1), beef (vertical column 2), and corn-meal (vertical column 3) agar media. A, *a–c*, and C, *d–f*.—Convolute type of growth, and A, *d–f*, B, *a–c*, and C, *a–c*, pulvinate type of growth, as determined particularly by the character of the colony on potato-dextrose agar. A, *a–c*.—Isolation from *Rosa gentiliana* (pl. 1); A, *d–f*, same isolation as that shown in Plate 6, E. B, *a–c*.—Isolation by Osterwalder (*35*), in 1926, from Jonathan apple grown in Switzerland. C, *a–c*.—Isolation by L. K. Jones, in 1923, from *Rubus occidentalis* L., Wisconsin. C, *d–f*.—Isolation by the writer, in 1925, from *R. neglectus* Peck, Virginia. Photograph of color drawings by J. Marion Shull

Crimson Globe and in a few other isolations, from both rose and brambles, made by the writer. As a rule, however, the coloration imparted to the media by these organisms is a pinkisn or reddish hue, sometimes "madder-red." This coloration was present to a greater or less degree throughout the media in all the cultures shown in Plate 7, vertical column 3, where the crescent-shaped discoloration beneath the colonies in B, *c*; C, *c* and *f*, is also due to this chromogenesis. As is often the case with old cultures of Sphaceloma, conidia are probably absent or sparse in all or most of the cultures shown in Plates 6 and 7. They were abundant in the cultures illustrated in Figure 2, A, *a* and *b*, and B.

In young cultures grown in parallel, conidia of *Elsinoe piri* were definitely smaller than those of *E. veneta*. No conidia could be found in a culture of *Sphaceloma rosarum* included in the same comparison. Harris, comparing conidia of this species from a rose stem canker with those of *E. veneta* taken directly from its bramble host, found them of nearly the same size; i. e., those of the rose fungus measured 5.9$\mu$ by 3.1$\mu$ and those of the bramble, 6.5$\mu$ by 3.0$\mu$, while cultures of the two were practically indistinguishable. The material of the rose fungus studied by Harris was taken from that sent to Wakefield by Buddin in 1926 (p. 65). This culture, not now living, was isolated by Wakefield; and the other culture, from brambles in England, was made by R. C. Harris. The conidia of *E. piri* referred to were from the isolation of this fungus from the Portuguese specimens of diseased apples contributed by Bensaúde (*27*); those of the parallel culture of *E. veneta*, from the isolation of that fungus shown in Plate 1, C, *d–f*.

## ASSOCIATED FUNGI

Associated with *Sphaceloma rosarum*, there has been found an Alternaria, as first noted by Massey and later by the writer, and also a yeastlike imperfect fungus and an ascomycete. The yeastlike fungus is probably similar to that which Stoneman (*41, p. 77*) found associated with *Gloeosporium venetum*, if not identical with it, and is possibly to be classified in the genus Phymatotrichum (*5, p. 116*) as typified by *P. gemellum* Bon. (*5, p. 116, fig. 138*), although not in this genus as emended by Duggar (*13*). It is certainly of the same form genus as *P. vaccarum* Oud. (*37, p. 392–394, figs. 7–10*) and various similar fungi, including a fungus apparently causing a rose blight, reported by the present writer as *Polyspora* ? sp.[25] and a "Dematium-like" fungus said to cause a blight of cherry (Prunus) (*10, Misc. Pub. 666, p. 109–112, figs. 122, a; 123, a–d; 124; 125*). The ascomycete on one occasion found in association with *S. rosarum* is identified as *Pringsheimia sepincola* (Fr.) Höhn. (*20, p. 97*). It may be noted that according to the synonymy given in the reference just cited *Sphaerulina intermixta* Berk. and Br. should be the same fungus. The writer was unable to demonstrate for the former ascomycete the "*Dematium pullulans*" which Brefeld (*6, pl. 7, figs. 47–50*) claimed that he obtained when he grew cultures of the latter from ascospores.

[25] MARTIN, G. H. DISEASES OF FOREST AND SHADE TREES, ORNAMENTAL AND MISCELLANEOUS PLANTS IN THE UNITED STATES IN 1924. U. S. Dept. Agr., Bur. Plant Indus. Plant Disease Rptr. Sup. 42 (p. 362), 380 p. 1925. [Mimeographed.]

### PATHOGENICITY

That *Sphaceloma rosarum* is the cause of rose anthracnose was proved by artificial inoculations made under greenhouse conditions at Ithaca, N. Y., on March 15, 1927. The plants inoculated were the Dr. W. Van Fleet rose, propagated in a greenhouse at Washington, D. C., by the Division of Gardens and Grounds, Bureau of Plant Industry, United States Department of Argiculture. The inoculum was a several-weeks-old potato-dextrose-agar culture of the isolation from *Rosa gentiliana* shown in Plate 7, A, *a–c*. Small masses of the culture, crushed and moistened in water, were forced between the closely folded halves of young leaflets, so that the fungus came in contact only or mostly with the upper leaf surface. Each of five leaflets so inoculated was wrapped in small pieces of cotton saturated with water; then the entire leaf, together with part of the stem from which it grew, was loosely wrapped in waxed paper. The coverings were removed after 48 hours. Except for the absence of inoculum, the five leaflets serving as checks were treated in the same manner as those inoculated.

On March 27, reddish lesions less than a millimeter in diameter had developed on the upper surface of the leaflets inoculated. These lesions when examined on April 2, had enlarged somewhat; a few showed whitish centers, and some had become visible also on the lower surface. Microscopic examination revealed the presence of the fungus in the lesions, and in reisolation cultures only growth of this fungus developed. The cultures were made by disinfecting in mercuric chloride (1:1,000) entire leaflets or parts of leaflets bearing lesions, rinsing them in sterile water, and transferring them to potato-dextrose-agar slants.

The rose plants used in the experiment just described were later inoculated with a culture of *Elsinoe veneta*, but in this instance there was no evidence of infection. Purplish blotches appeared within a day or so on the inoculated leaves but were not typical of rose anthracnose, and no organism was reisolated from them. Essentially the same results were obtained when, likewise under greenhouse conditions, tender leaves of young seedling apple trees were inoculated with a cultural growth of *E. veneta*, as well as of Sphaceloma from unrelated hosts. The inoculated leaves were left on the trees, and after a time the discoloration entirely disappeared. In this connection Alexander's (*1, p. 71, 72*) inoculations with *Gloeosporium venetum* Speg., i. e., *E. veneta*, should be noted. He states (*1, p. 71*) that under "very * * * humid conditions" this organism "produced a slight lesion on *Opuntia inermis* after 48 hours," and (*1, p. 72*) that it produced a "considerable amount of rot" on apple fruits "within 24 hours." He does not report reisolations from either pricklypear or apple, nor does he explain whether this decay occurred on the apples inoculated by inserting the pure culture into the tissue with a needle or on those sprayed with conidia, or on both.

### CONTROL

The only control measures known to have been reported for rose anthracnose are those by Cobb (*10, p. 1064–1065*) and Marchionatto (*33, p. 13*). The former advises the removal and destruction of affected parts and, where the disease is severe, spraying with Bordeaux

mixture; the latter recommends spraying with this fungicide or with ammoniacal copper carbonate as the disease appears. From Naito it was learned that in Japan the disease is controlled by spraying with Bordeaux mixture. During the last few years, Erlanson, following the suggestion of the present writer, controlled the disease in the wild-rose garden at the University of Michigan botanical gardens and arboretum at Ann Arbor by spraying the roses with lime-sulphur before the leaf buds opened and with Bordeaux mixture after the leaves had developed. This is an adaptation of the recommendations given by Bennett (*4*) for the control of bramble anthracnose in Michigan.

## SUMMARY

Rose anthracnose has been confused with a number of other rose diseases, and for this reason has not been generally recognized as a distinct disease. It is of considerable economic importance, affecting many rose species and varieties and including in its range the United States, Canada, Argentina, Japan, China, New South Wales, most European countries, and Africa. Its occurrence in France in 1828 and in the United States in 1869 is reported. The pathogene, *Phyllosticta rosarum*, described by Passerini on the basis of material that he collected in Italy in 1881, is here transferred to the genus Sphaceloma as *S. rosarum* (Pass.), n. comb. Morphological and cultural characteristics of the fungus are given, together with proof of its being the cause of rose anthracnose. Fungi associated with *S. rosarum* are mentioned, symptoms of the disease described, and the available information pertaining to its control is summarized.

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# A BACTERIAL DISEASE OF THE TUNG-OIL TREE[1]

By LUCIA MCCULLOCH, *Associate Pathologist*, and J. B. DEMAREE, *Pathologist*, *Division of Horticultural Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture*

## INTRODUCTION

A bacterial leaf spot of the tung-oil or wood-oil tree (*Aleurites fordi* Hemsl.) was observed by Boyd[2] in several localities in southern Georgia in 1929. The first specimens of diseased leaves received by the senior writer were collected by Doctor Boyd October 25, 1929, from a nursery in southwestern Georgia. Infected leaves of the same season's growth were collected later by the junior writer. Numerous petiole and stem lesions on material from Georgia have also been examined, but so far no microscopic evidence of bacteria has been found in these, and efforts to isolate bacteria have been unsuccessful.

In 1930 and 1931 this bacterial disease was either absent or so slight as to escape observation. This freedom from the disease may have been due to the unusually dry weather during the growing seasons in the sections where the tung-oil trees are grown. In the numerous collections made in the field at various times during the seasons of 1930 and 1931 no typical leaf lesions were found. Cultures were made from all suspicious spots in these collections, but the characteristic pathogene was not found. The distribution of the disease is not well known, nor is the amount of damage it is capable of causing. During periods of moist, hot weather, especially with wind and rain to distribute the bacteria, the disease may become serious. According to Boyd,[3] infection occurs on trees of all ages but is more likely to be destructive to the 1-year-old and 2-year-old stock.

In March, 1931, the senior writer examined several orchards in the vicinity of Gainesville, Fla., but found no evidence of the disease on either the new leaves or the dry, fallen leaves of the previous year's growth.

## THE DISEASE

The following description of the disease is based on naturally infected leaves collected in Georgia and on artificially infected greenhouse plants in Washington, D. C.

The general appearance of infected leaves is shown in Figures 1 and 2. Mature, isolated lesions are distinctly angular in shape and are dark brown to black ("bister," "sepia" to "mummy brown")[4] on the upper surface and somewhat lighter in color on the lower surface. A definite narrow border darker than the center is usually noted, and a wide, indefinitely margined, yellowish halo surrounds

[1] Received for publication Feb. 17, 1932; issued October, 1932. The investigation herein reported was originally planned by the senior writer in collaboration with O. C. Boyd, a collaborator of the Department of Agriculture, formerly at Thomasville, Ga., now extension plant pathologist of the Massachusetts State College. In accordance with a suggestion made by Doctor Boyd when he left Georgia, the work was carried out in collaboration with the junior writer, who was stationed at Thomasville.

[2] BOYD, O. C. A BACTERIAL DISEASE OF TUNG-OIL TREE. (Pathological Note) Phytopathology 20: 756-758, illus. 1930.

[3] BOYD, O. C. Op. cit.

[4] The color readings in this paper are based on the following publication: RIDGWAY, R. COLOR STANDARDS AND COLOR NOMENCLATURE. 43 p., illus. Washington, D. C. 1912.

very active infections. Under average conditions the progress of the infection is soon checked by the larger leaf veins, resulting in the formation of isolated angular lesions, 1 to 20 mm wide. The infected tissues are dull, dry, and opaque, often shriveling and cracking; there is no exudate. Infections are first evident as small, greenish, translucent spots, which soon become brown, opaque, and angular. The active advance of the infection is marked by a translucent border, which is lost when a vein becomes the boundary line. Only

FIGURE 1.—Typical lesions on leaf of tung-oil tree, artificially infected. × ¾

occasional mature lesions have translucent margins. When conditions are unusually favorable for the parasite, the infection spreads rapidly over large areas regardless of veins. (Fig. 3.) Lesions occur on all parts of the leaf blade; they are usually well distributed but are most numerous in areas where moisture is most abundant. The vascular system is not invaded, but veins within a lesion are dry and distorted.

Infections, which enter through the stomata,[5] are often extensive enough to cause the destruction of the entire leaf.

[5] Stomata are fairly numerous (35 to 40 to the square millimeter) on the lower leaf surface of *Aleurites fordi*. On the upper surface there are from 0 to 7 stomata to a square millimeter, and these few are located along the larger veins.

## ISOLATIONS AND INOCULATIONS

The bacteria are abundant in the lesions and are easily isolated by the usual methods. Several isolations were made from the naturally infected leaves of the two collections of 1929, and numerous isolations have been made from leaves artificially infected. Dead, fallen leaves bearing numerous typical lesions were collected from a Georgia orchard in February, 1930. These leaves had probably been on the ground since October. Typical infectious bacteria were isolated from

FIGURE 2.—Leaf of tung-oil tree, four days after inoculation. Plants held at 28° to 32° C. and sprayed with water twice each day. × ½

these old leaves as late as April, 1930. Isolation tests in May, 1930, from these old leaves were not successful.

Small tung-oil trees were secured from Florida and established in a greenhouse in Washington, D. C.; a number of others were grown from seed. All the plants grew rapidly and, except when inoculated, remained free from disease.

The first inoculations were made in May, 1930, on 2-year-old trees, with subcultures of the bacteria isolated in November, 1929, from the leaves from Georgia. Bacteria from agar-slant cultures were suspended in water and sprayed on the plants, which were then placed in a moist inoculation chamber for 24 hours. Infection was evident in 3 to 4 days, and characteristic spots of good size developed in 6 to 8

days at a temperature of 28° to 32° C. From these induced lesions pure-culture reisolations, made May 14, 1930, were used on May 19, 1930, to inoculate tung-oil leaves, which were successfully infected. Numerous other inoculations in 1930 and 1931 have consistently produced the characteristic infection.

Infection was most active when the plants were kept in a moist atmosphere for 24 to 48 hours. A moderate amount of moisture

FIGURE 3.—Leaf of tung-oil tree, showing large areas infected under unusually favorable conditions of moisture. × ½

seems necessary for the production of large lesions. If the moisture is excessive, so that a film of water is retained on the leaves for hours, the infection is more intensive and, instead of isolated angular lesions, produces wide continuous areas of browned tissue, sometimes involving the whole leaf. Plants on the bench, under only the usual greenhouse conditions of moisture, were slow in showing infection, and the lesions were usually small.

Successful infections were secured by the junior writer in the field from inoculations made with two different strains of the bacteria.

One of these strains was isolated in March, 1930, from old weather-beaten tung-oil leaves from a Georgia orchard; the other was a reisolation from bean leaves infected with the tung-oil bacteria. These field inoculations were made in Georgia in 1931 during a period of dry weather, and the resulting lesions were small and rather slow in developing.

No infections have been secured on petioles or on stems of the inoculated tung-oil plants, either by means of needle-prick wounds or bruising, or by keeping the inoculated areas moist for several days.

The castor-bean (*Ricinus communis* L.), a plant related to the tung-oil tree, on which a bacterial leaf spot has been reported,[6] was inoculated with the tung-oil organism under the same conditions of temperature and moisture as were the tung-oil plants. Infection occurred as leaf spots and occasionally as an interior rot of the hollow petioles. The infection was slow in developing, and leaf spots were never numerous. Leaf spots on Ricinus are pale yellow or light brown, irregularly circular, and mostly small, though a few spots reach 10 mm in diameter. The tissue lining the hollow stalk was blackened, while the exterior remained normal in appearance. Isolations from leaf and petiole infections of Ricinus were secured, and these when tested on tung-oil leaves produced the original type of infection. The characters of the bacterium previously reported [7] as causing a leaf spot on Ricinus are quite unlike those of the bacterium described in the present study.

The bacteria causing the lesions on the tung-oil leaves have characters very similar to those of some known pathogenes of beans. It was at first thought that the disease had spread from some legume used as a cover crop in the orchards. However, cultural studies and comparisons showed that the tung-oil organism differed from all those described from the legumes. It is possible that the infection spread from a bacterial disease of some wild or cultivated plant growing in the vicinity of the tung-oil orchards.

Five varieties of beans (Red Kidney, Bountiful, Giant Stringless Green Pod, Black Valentine, and Refugee) are very susceptible to the tung-oil bacteria. When sprayed with the bacterial suspension, leaves of these varieties quickly developed isolated spots and large areas of thin, transparent tissue. Veins in the infected parts or adjoining them became bright reddish brown, the discoloration often extending a considerable distance beyond the leaf lesion and even into the petiole. The leaves were usually so seriously damaged that they fell in a few days. The slight vascular invasion in the leaf tissue did not extend into the stem; and, except in cases of direct contact, the infection did not spread to leaves other than those inoculated. When tested by inoculation on the tung-oil leaves, reisolations from all these bean infections proved that the infections were due to the tung-oil organism.

Tobacco plants were inoculated several times, but no infections resulted.

[6] YOSHI, H., and TAKIMOTO, S. [BACTERIAL LEAF BLIGHT OF CASTOR BEAN.] Byôchû-Gai Zasshi (Jour. Plant Protect.) [Tokyo] 15:12-18. 1928. [In Japanese.]
[7] YOSHI, H., and TAKIMOTO, S. Op. cit.

## THE PATHOGENE

### MORPHOLOGY

When grown on beef-infusion media 24 to 48 hours at 26° to 28° C., the causal organism is a rod with rounded ends, 1.1 to 3$\mu$ long by 0.6 to 0.7$\mu$ wide, its usual size being 1.8 by 0.7$\mu$. It occurs singly, in pairs, or in short chains. It is motile by means of 1 to 5 polar or, rarely, bipolar flagella. Capsules are present. No spores have been found. The organism is Gram-negative; not acid-fast. It stains readily with the usual bacterial stains.

### CULTURAL CHARACTERS

BEEF-AGAR PLATES.[8]—On beef agar, under favorable conditions, colonies 1 mm in diameter appear in 24 hours. In two days well-isolated colonies are 1 to 4 mm wide, increasing in six days to 7 to 8 mm wide. At first white, or rather like boiled starch, and translucent, they soon become greenish white and transparent. They are smooth, shining, flat, mostly circular with an entire margin, occasionally becoming crenate to lobed. The interior is definitely striated or cross-hatched except in small, much-crowded colonies. Frequently a zone of pure white occurs at, or just within, the margin. Large colonies occasionally show 1 to 3 widely separated concentric markings. Bacteria isolated from young vigorous lesions often produce large, lobed colonies; otherwise the colonies from old lesions (2 to 7 months old) and from young lesions are alike. Submerged colonies are opaque, white, oval to spindle shaped. The medium is greened and has an unusual, rather sweetish odor.

BEEF-AGAR SLANTS.—Growth is thin, white, transparent, sometimes slightly viscid. The agar greens promptly. Numerous tiny crystals form on the slanted surface, and long, slender, needle-shaped crystals extend into the agar at right angles to the slant.

BEEF-AGAR STABS.—There is a moderate surface growth, greenish white. Growth occurs only in the upper few millimeters of the stab. In 6-months-old cultures numerous, short, rodlike crystals are present, uniformly distributed throughout the agar.

BEEF-BROTH.—A heavy, white, surface growth forms within 24 hours. This growth, at first tender and easily dissolved, is renewed after each disturbance, increasing in density until, after four to five days, it is more like a true pellicle. In undisturbed cultures, clouding below the surface is slow in developing. Narrow white rims are sometimes present. The sediment is whitish, translucent, rising in a spiral when rotated and dissolving easily. Greening of the broth begins at the surface and is complete in four to six days. Cultures four to eight weeks old have uniform clouding and no pellicle or rim. Clouding persists for four to five months.

POTATO CYLINDERS.—A rather scanty growth, smooth, dull yellowish white, develops on potato. The potato and the water are slightly browned.

THAXTER'S POTATO-DEXTROSE AGAR.—On this medium the growth is heavier than on beef agar and almost brown in the thicker parts.

CORN-MEAL AGAR.—No growth occurs on this medium.

COHN'S SOLUTION.—Growth in Cohn's solution with a pH of 5.2 is prompt and as good or better than in beef broth. There is a heavy surface growth, with numerous tiny floating crystals. Undisturbed cultures show horizontal bands of clouding, the heaviest at the top. The clouding and the production of surface crystals persist for weeks. There is a moderate, white sediment over a layer of tiny crystals. The medium becomes slightly green or pale straw color.

USCHINSKY'S SOLUTION.—There is a fairly heavy surface growth in 24 hours, and heavy, tender white pellicles in two days. Clouding becomes uniform by the tenth day. A fine blue-green fluorescence develops.

[8] Unless otherwise noted, the beef media used were made with beef infusion and peptone and had a pH value of 6.8 to 7.0. Cultures were grown at room temperature.

PHYSIOLOGIC CHARACTERS

LIQUEFACTION OF BEEF GELATIN.—Well-isolated colonies in poured plates are 3 to 8 mm wide in six to seven days. They have a rather thick, slightly elevated, central area of granular to mottled structure, surrounded by a wide, very thin border, irregularly and often deeply lobed. Colonies are greenish white and transparent. In stab cultures there is good surface growth. There was no trace of liquefaction in plate or tube cultures held for eight weeks at 18° to 20° C.

LIQUEFACTION OF BLOOD SERUM.—Very scanty growth develops, and there is no clearing and no liquefaction.

PRODUCTION OF AMMONIA.—Ammonia production is very slight in a peptone-glucose dipotassium phosphate medium, and apparently absent in other media.

PRODUCTION OF HYDROGEN SULPHIDE.—Lead acetate paper suspended over cultures of various media indicates a very slight production of hydrogen sulphide.

PRODUCTION OF INDOL.—Cultures eight days old in 2 per cent peptone solution give a positive reaction for indol about one-half as strong as the check cultures of *Bacillus coli communis*.

TOLERATION OF SODIUM CHLORIDE.—In beef broth containing 1 to 2 per cent sodium chloride the bacteria grow readily. With 3 per cent sodium chloride the growth is considerably retarded, and very slight growth occurs in a 5 per cent solution.

HYDROLYSIS OF STARCH.—On starch-agar plates streaked with the organism, an area 7 to 10 mm wide beyond the growth is cleared within 10 days. In potato cylinders there is very little evidence of starch destruction.

RELATION TO FREE OXYGEN.—In solid media the growth occurs only at or very near the surface. There is no growth in the closed ends of fermentation tubes or on inoculated surfaces so covered as to exclude air.

REACTION IN MILK.—There is no separation of the milk, but old cultures (five to eight weeks old) are very slightly less opaque than the controls. There is a slight color change to cream-buff, or even a lighter color, and evaporation rims of chamois. Oil globules are deep rose pink. Litmus milk is blued. The endive blue to Dutch blue in 3-day-old cultures gradually deepens to dark green blue gray and then to slate gray in cultures three to six months old. There is a slight, fugitive reduction of the litmus in the lower third of the tubes. In one lot of medium containing less than the usual amount of litmus there occurred a practically complete reduction, lasting for 24 to 48 hours. There is a small amount of white sediment. Oil globules are deep rose to red.

METHYLENE BLUE IN MILK.—In two days the lower half of the tubes shows reduction and in five days the reduction is complete. The color returns within three weeks. In some tests there was a second reduction, followed by another return of color slightly greener than the controls.

REDUCTION OF NITRATE.—A decided nitrate reduction is evident in cultures 9 days old and a stronger reaction in cultures 12 to 18 days old, when the α-naphthylamine sulphanilic acid test is used. Parallel cultures tested with starch potassium iodide, and sulphuric acid show no nitrite reaction.

FERMENTATION OF CARBOHYDRATES.—Various sugars and alcohols were tested for fermentation. The carbohydrates were added to a synthetic agar made according to the formula in the Manual of Methods [9] with brom cresol purple for the indicator. Growth and acid reactions were prompt from dextrose, galactose, glycerin, and mannite, the yellow color extending to the base of the slants in 24 hours. No growth and no color change occurred in saccharose, lactose, or maltose. Results were identical in five different tests.

With the same series of carbohydrates in fermentation tubes [10] (same medium base but lacking agar) acid was evident in 24 hours from dextrose, galactose, and mannite. Glycerin showed acid reaction in two days. A few saccharose cultures showed slight growth and yellow color on the sixth day and others on the tenth day. After 15 days, growth and yellow color were observed in some of the maltose and lactose cultures. Cultural tests proved that these were pure cultures of the tung-oil organism. No gas was formed from any of these carbohydrates in the fermentation-tube cultures, and clouding was confined to the open ends of the tubes.

TOLERATION OF ACID AND ALKALI.—In beef broths ranging from pH 5.2 to 9.2 clouding occurs within 24 hours at pH 5.6 to 8.8, but is heaviest at pH 6.2 to 6.8. In two days there is slight growth at pH 8.9 and in five days at pH 5.4. In

[9] SOCIETY OF AMERICAN BACTERIOLOGISTS, COMMITTEE ON BACTERIOLOGICAL TECHNIQUE. MANUAL OF METHODS FOR PURE CULTURE STUDY OF BACTERIA. 48 p., illus. Geneva, N. Y. 1928.

[10] The fermentation tubes were steamed on three successive days. The agar tubes were sterilized under pressure.

Cohn's solution with a pH of 5.2 the organism makes a prompt, almost heavy growth.

RESISTANCE TO DESICCATION.—Bacteria from young beef-broth cultures were dried at room temperature on sterile cover glasses. At least a few bacteria survived for five weeks, but after drying for two days the majority of the covers failed to produce growth. The bacteria were alive in lesions on tung-oil leaves kept dry at room temperatures for four months. Bacteria in leaves lying on the ground in the orchard from the time of defoliation, October (?), until February of the following year retained vitality and pathogenicity until April.

VITALITY IN CULTURE MEDIA.—In beef media and in Cohn's solution the bacteria remain alive at least 11 months.

TEMPERATURE RELATIONS.—The best growth takes place between 27° and 28° C. At 10° to 12° beef broth clouded well in 48 hours. At 37° a very scanty growth, in the form of small isolated colonies on beef agar, appeared after two weeks. No growth was evident in liquid media at 37°. At 37.5 there was no sign of growth, but the organism remained alive for at least 14 days. At 35° moderate growth occured in 24 hours and increased until by the sixth day the clouding was heavy. These cultures remained alive at 35° for at least 48 days. The thermal death point is 52°. Here again there is an uneven resistance. Some cultures held at 48°, 49°, 50°, and 51° for 10 minutes failed to grow, and occasionally those held at 52° clouded. There was never any growth in the tests at 53°.

## TECHNICAL DESCRIPTION

**Bacterium aleuritidis,** n. sp.

A motile rod 1.1 to 3$\mu$ long by 0.6 to 0.7$\mu$ wide; 1 to 5 polar flagella, rarely bipolar; capsules present; no spores; Gram-negative; not acid-fast; colonies on beef agar are circular to slightly lobed, white, translucent, becoming greenish white and transparent. Clouds beef bouillon and forms a pellicle; gelatin not liquefied; produces a green fluorescence in all beef media; blood serum not cleared or liquefied; moderate diastatic action; acid without gas readily produced from dextrose, galactose, glycerin, and mannite; growth and production of acid slow from saccharose, lactose, and maltose; reduces nitrates; produces indol, ammonia, and hydrogen sulphide in slight amounts; aerobic; trace of peptonization of milk; litmus in milk shows a slight, fugitive reduction; litmus blues and remains blue. Excellent growth in Cohn's solution. Grows best at pH 6.2 to 6.8; irregular resistance to heat and desiccation; a few organisms survive cover-glass drying for five weeks; in herbarium leaf specimens and in dead leaves in the orchards the bacteria survive for at least four months. The optimum temperature for growth is 27° to 28° C., maximum temperature 37°. Dark brown, angular spots are produced on the leaves of the tung-oil tree (*Aleurites fordi*). Moderate infection is produced on the leaves of castor-bean (*Ricinus communis*), and serious infection on at least five varieties of beans (*Phaseolus* sp.).

Specimens of tung-oil leaves with lesions produced by this organism have been deposited in the pathological and mycological collections of the Bureau of Plant Industry, United States Department of Agriculture.

## SUMMARY

A bacterial disease of the tung-oil tree (*Aleurites fordi* Hemsl.), as yet reported only from Georgia, produces brown, angular spots on the leaves. Defoliation results when considerable leaf tissue is affected. Moisture and heat favor the occurrence and spread of the disease. The bacteria probably remain alive and infectious in the lesions of fallen leaves in the orchards until new leaves appear the following spring. Such leaves are doubtless a factor in the recurrence of the disease. The causal bacteria have been isolated and used to produce typical lesions on tung-oil leaves. The bacteria are only slightly infectious on leaves of castor bean (*Ricinus communis* L.). On several varieties of bean (*Phaseolus* sp.) the infections due to these bacteria were very severe.

A description is given of the morphologic, cultural, and physiologic characters of the pathogene, for which the name *Bacterium aleuritidis* is proposed.

# DETECTING PINK BOLLWORMS IN COTTONSEEDS BY THE X RAY[1]

By F. A. FENTON, *Senior Entomologist, Division of Cotton Insects, Bureau of Entomology, United States Department of Agriculture,* and WILLIS W. WAITE, *Director, Southwestern Biological Laboratories,* in cooperation with the *Texas Agricultural Experiment Station*

In studying the hibernation of the pink bollworm, *Pectinophora gossypiella* Saund., and in comparing the effects of different combinations of plowing and irrigation as control measures for this insect, it has been necessary to examine hundreds of dry cotton bolls and cut thousands of seeds in order to determine mortality percentages. Owing to the extreme hardness of cottonseed this was extremely slow and tedious work. An effort was made, therefore, to discover a more rapid and efficient method of seed examination. Several samples were examined by means of a fluoroscope in a darkened room, but this procedure was not found effective. It was then suggested that an X-ray photograph might show the live worms inside of the seed. Although this operation would be too expensive for regular use with the limited number of seeds to be examined, it was of interest to determine the possibilities of the method. Several exposures were made of both delinted and undelinted ginned seed, as well as of locks of cotton with the seeds in their normal position. It was found possible to detect immediately the presence of live or dead larvae within the seed. The results were so striking that the method seems well worth recording.

As previously stated, delinted seed, seed direct from the gin, or seed with the cotton attached can be used. Ginned seed is just as good as delinted seed and eliminates the work of delinting. Unginned seed occupies too much room on the film, and inasmuch as seeds in the cotton are often superimposed upon one another, it may be impossible to get a clear picture of all of them.

The seeds are best put out in rows, one layer deep, over the film. The rows may be close together and the seeds in the rows may touch one another. With this arrangement the film can be examined easily, and it is possible to count both the infested and the imperfect seeds.

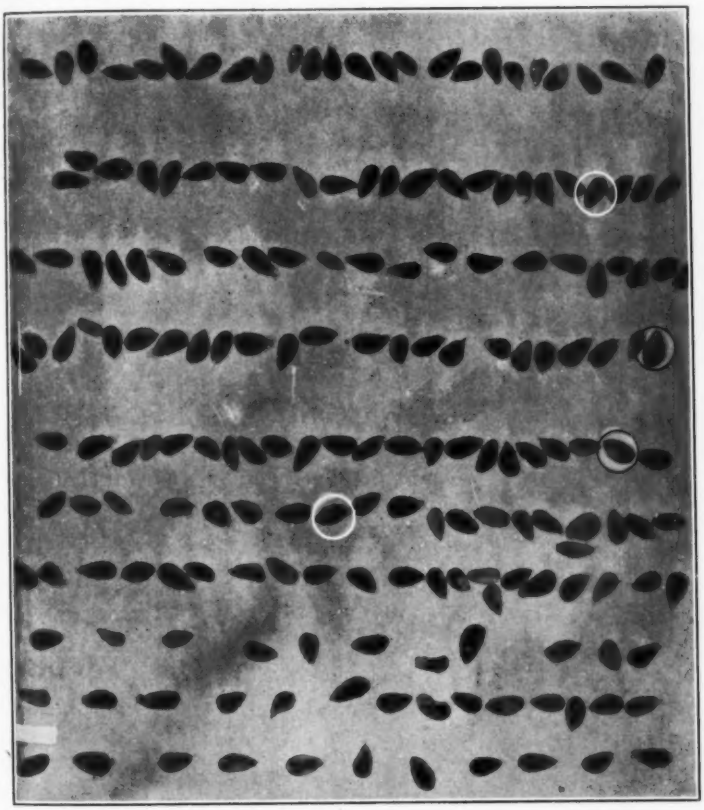
If it is desirable to check up the bad seeds found in the film, the seeds should be placed on some sort of a channel or cover over the film so that the film can be removed without disturbing the seeds. A film mounted in a cardboard holder is sufficient. Intensifying screens are unnecessary. Very little exposure is needed, so any sort of X-ray machine is suitable for making the pictures. With a little experience just the right exposure can be determined.

[1] Received for publication Feb. 1, 1932; issued October, 1932.

The examination of the film is aided by the use of a good hand lens. The perfect seeds show up well, without defects. The imperfect seeds and infested seeds are not so easily distinguished, since many imperfect seeds are in this condition because the worms have bored into them. In other seeds the worms are dead and shriveled. The live worms give a fairly characteristic picture, and after a little study and checking of the film with actual examination of the seed, one soon becomes familiar with their appearance (pl. 1) so that it is sufficient to rely on the picture alone for their detection.

It is possible to photograph a thousand seeds at once, and it takes only a few minutes to arrange the seeds and make the exposure. By having plenty of films ready a large number of photographs can be taken in a short time. These films can then be developed and kept as a permanent record.

Detecting Pink Bollworms in Cottonseeds by the X Ray PLATE 1



X-ray photograph of cottonseeds, showing two (in white circles) infested with live pink bollworms and two (in black) infested with dead worms

# THE EFFECT OF THE DEGREE OF SLOPE ON RUN-OFF AND SOIL EROSION [1]

By F. L. DULEY, *Professor of Soils*, and O. E. HAYS, *Graduate Assistant in Soils, Department of Agronomy, Kansas Agricultural Experiment Station*

## INTRODUCTION

The degree of slope of land has long been considered one of the major factors governing the amount of run-off and soil erosion. Few attempts, however, have been made to establish even the most simple mathematical relationships between the degree of slope of land and the amount of run-off and erosion. While at the university of Missouri, the senior author, in collaboration with Prof. M. F. Miller,[2] reported the results of erosion measurements begun in 1917 on a 3.68 per cent slope. In 1924 additional plots were installed on a 6 per cent and on an 8.25 per cent slope.

The work on these plots, involving three slopes, has been continued at the Missouri station, and a preliminary report has been made by Miller.[3] The chief difficulty encountered in this type of study is that when slopes of different degrees and in somewhat separated locations are chosen, the soil profiles are not identical. The surface soils also are likely to be widely different in absorbing power since they have developed under a different set of conditions. In the work reported in the present paper two methods have been used for determining the effect of slope on the amount of run-off and erosion, in which attempts have been made to eliminate the soil variations referred to above.

## METHODS

### LABORATORY TESTS

One of the two methods may be termed a laboratory method. A galvanized-iron tank 24 inches wide, 28 inches deep, and 10 feet long was surrounded by heavy framework, as shown in Figure 1. This method was somewhat similar to that reported by Lowdermilk [4] for studying certain questions in connection with forest soils. A silty clay loam soil with a fairly heavy clay subsoil from the agronomy farm was removed in 6-inch layers from a plot exactly the same size as the tank. The soil was placed in the tank in the same order as it existed in the field and was carefully tamped in until it occupied the same volume as it did in the field. Before putting in the soil a 2-inch layer of sand was placed in the bottom of the tank to provide thorough underdrainage, and the excess water was removed through a small drainage tube. The sides of the tank extended 2 inches above the surface of the soil, except at one end where the iron was turned

[1] Received for publication Jan. 19, 1932, issued October, 1932. Contribution No. 214 Department of Agronomy, Kansas Agricultural Experiment Station.

[2] DULEY, F. L., and MILLER, M. F. EROSION AND SURFACE RUNOFF UNDER DIFFERENT SOIL CONDITIONS. Missouri Agr. Expt. Sta. Research Bul. 63, 50 p., illus. 1923.

[3] MILLER, M. F. EROSION AS A FACTOR IN SOIL DETERMINATION. Science (n. s.) 73: [79]-83. 1931.

[4] LOWDERMILK, W. C. INFLUENCE OF FOREST LITTER ON RUN-OFF, PERCOLATION, AND EROSION. Jour. Forestry 28: 474-491, illus. 1930.

down level with the soil to permit run-off. When complete this tank equipment with soil and water weighed about 2.5 tons.

Differences in slope of the soil surface in the tank were obtained by raising one end by means of jackscrews or a differential hoist. A slope of about 20 per cent was as much as it was found possible to give this

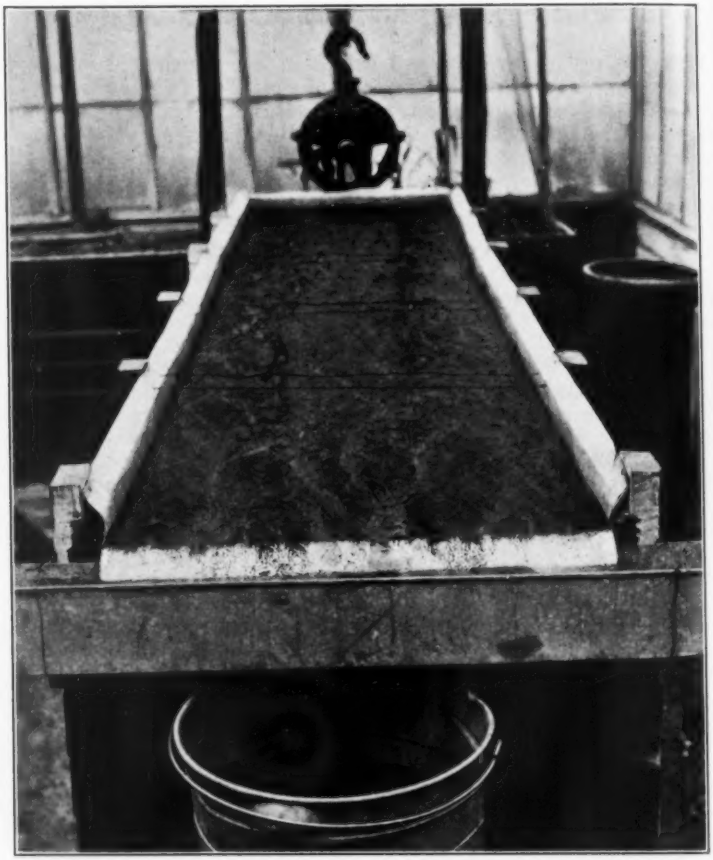


FIGURE 1.—Tank filled with soil and used in greenhouse to determine the effect of slope of the soil on run-off and soil erosion. By raising one end of the tank any desired degree of slope may be obtained

block of soil without throwing undue strain on the tank and framework. A later test, however, was made with a 40 per cent slope.

## FIELD TESTS

A second method of determining the effect of slope on run-off and erosion was carried out in the field. In this work an attempt was made to eliminate soil variation by using plots placed at different

angles on the same slope. By properly placing the plots, slopes varying from 0° to the maximum slope of the hillside can be obtained. This method is illustrated in Figure 2.

The plot was surrounded by strips of galvanized iron set in the ground to depths of about 8 inches. The iron extended about 2 inches above ground, and the upper edge was turned to prevent bending. At the lower end the edge was turned down about 2 inches until the top was on a level with the soil surface, and the narrow apron thus formed turned down into a small metal gutter which was used for carrying the run-off water and eroded soil into a bucket.

The plots were then leveled crosswise so that there was a slope in only one direction, and the slope lengthwise the plot was made uniform by carefully checking with a line. Some objection might be raised to this leveling process, but fairly deep soils were chosen so that the change in depth of surface soil would not be great and the

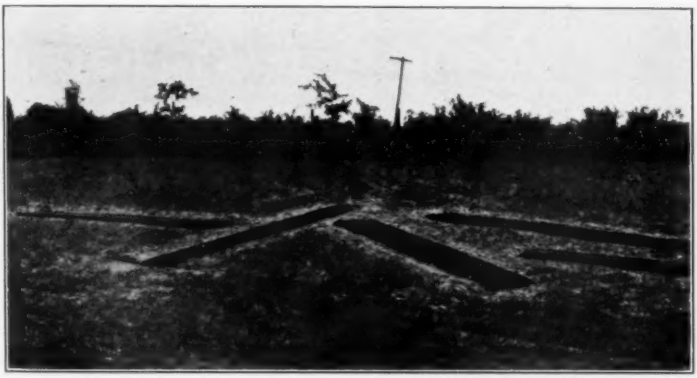


FIGURE 2.—Plots located at different angles on a hillside to obtain different degrees of slope on the same soil. The iron frame used to surround the plots has been removed

subsoil would not be disturbed. Since the plot used was only 34.85 inches wide, it was necessary to transfer only a small amount of soil from the upper to the lower side in order to make the surface level crosswise of the plot. The soil was then spaded to a uniform depth and carefully worked on the surface with a hoe and garden rake so that the amount of loose soil was the same over the entire plot. Care was taken that there were no holes or loose places which would cause irregular settling or uneven absorption of water.

Water was applied to the soil by means of a spinkling can. The rate of application was carefully timed so that any desired rate of rainfall could be imitated. Several mechanical methods of applying water by means of sprinklers were tried, but it was found that, if carefully used, the sprinkling-can method was the most satisfactory.

The run-off water and eroded soil were collected and weighed, and samples were taken for determining the amount of eroded soil.

## EXPERIMENTAL RESULTS

### TANK EXPERIMENTS

#### EFFECT OF SLOPE ON RUN-OFF

The tank of soil was thoroughly soaked with water before any measurements were made. This was done so that the results from different slopes would be comparable. The water was then applied at the rate of 1 inch an hour. By carefully timing the application, it was possible to keep an almost constant application of water. The amounts of run-off and erosion were first determined for a zero slope, or level land. The slope was then increased and the water and soil loss determined. The results of four sets of determinations are shown in Table 1. The average of the four determinations have been plotted on a curve. (Fig. 3.) The most significant thing about these results,

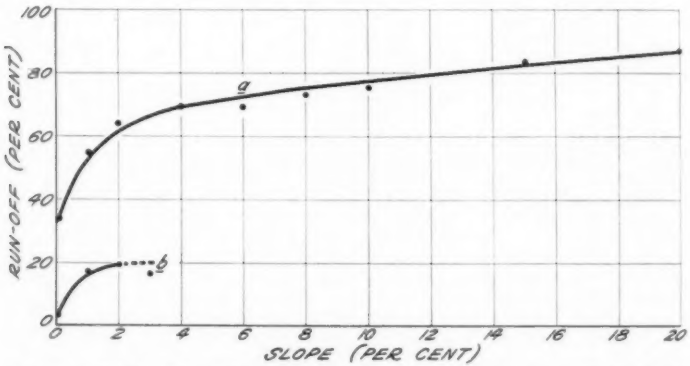



FIGURE 3.—Relation between the degree of soil slope and the percentage run-off: (*a*) Results obtained in Kansas when using soil tank in greenhouse with silty clay loam soil and (*b*) at Spur, Tex., with field plots. Broken part of this curve shows where it might be expected to fall for 3 per cent slope

as indicated by the curve, is the very rapid rise in the rate of run-off as the slope is increased from 0 to 2 per cent, followed by a more gradual rise to between 3 and 4 per cent. After this there is a very much slower rise in the curve. These results seem to indicate that on level land there may be a considerable amount of run-off, but when there is a slight slope the water is less hampered by the very slight depressions and runs off in much greater amounts before it can be absorbed; that is, it will not be held on the land much longer than the duration of the rain. With a still further increase in slope, the increase in run-off becomes relatively less because the water on any slope is running over the land for the entire duration of the rain and thus time is afforded for absorption. Any run-off that may be taking place at the end of the rain will cease within a short time whether the slope is slight or steep.

TABLE 1.—*Effect of slope of tank on run-off water from surface of soil*

[Water applied at rate of 1 inch an hour; size of tank 2 by 10 feet]

| Slope | Quantity of run-off water | | | | | Average run-off |
|---|---|---|---|---|---|---|
| | Jan. 25, 1931 | Jan. 31, 1931 | Feb. 21, 1931 | Feb. 28, 1931 | Average | |
| *Per cent* | *Pounds* | *Pounds* | *Pounds* | *Pounds* | *Pounds* | *Per cent* |
| 0 | 38.1 | ---------- | 20.4 | 47.2 | 35.2 | 33.85 |
| 1 | 57.8 | 52.2 | 45.8 | 70.5 | 56.5 | 54.33 |
| 2 | 61.8 | 65.9 | 59.5 | 76.8 | 66.0 | 63.47 |
| 4 | [a] 72.0 | 70.5 | 62.8 | 81.2 | 71.6 | 68.86 |
| 6 | 80.8 | 62.3 | 72.7 | ---------- | 71.9 | 69.15 |
| 8 | 83.3 | 70.7 | 74.7 | ---------- | 76.2 | 73.28 |
| 10 | 82.3 | 72.6 | 76.3 | 81.5 | 78.2 | 75.21 |
| 15 | ---------- | ---------- | ---------- | 86.8 | 86.8 | 83.48 |
| 20 | ---------- | ---------- | ---------- | 89.9 | 89.9 | 86.45 |

[a] 4.16 per cent slope.

## EFFECT OF SLOPE ON SOIL EROSION

An examination of Table 2 and Figure 4 will show that the effect of slope on erosion is almost opposite to that on run-off. The amount of soil removed increased very slowly as the slope was increased up to about 3 or 4 per cent. Then with increasing slope there was a very rapid rise in the amount of soil removed. This shows that with only a very low gradient when the water runs at a relatively slow rate, the soil is not picked up, and the water flows away without carrying much soil, except the lighter particles; but when the slope is increased, the water runs faster, and even though the average depth may be less, a far greater amount of soil is removed. The number of pounds of water required to remove 1 pound of soil decreases rapidly with increasing slope, as shown by Table 2. In a few cases the 0 and 1 per cent grades required a smaller amount of water to remove a pound of soil than did the next higher grades. Further tests are needed to establish this point definitely.

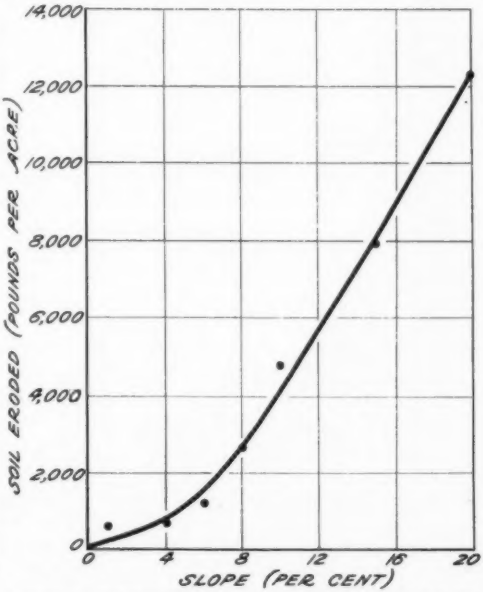



FIGURE 4.—Relation between the degree of soil slope and the quantity of soil eroded from silty clay loam soil in the tank in the greenhouse. Dots show average actual values

In the fall of 1931 the tank was filled with sandy loam with a sandy subsoil from the soil near St. George, Kans., where the field tests were made. The soil was thoroughly soaked with water so that drainage was taking place from the bottom before the readings were started. This made it possible to have the soil in approximately a uniform condition during the time the readings were being made for the various slopes. On November 2 water was applied equivalent to 1 inch an hour. One week later another set of readings was made. At this time the water was applied at the rate of 1 inch in 30 minutes. Tables 3 and 4 give the results obtained.

TABLE 2.—*Soil eroded (pounds) from silty clay loam in greenhouse tank at different percentages of slope*

[Water applied at rate of 1 inch an hour]

| Slope | Soil eroded | | | | | | Run-off required to remove 1 pound of soil |
|---|---|---|---|---|---|---|---|
| | Jan. 24, 1931 | Jan. 31, 1931 | Feb. 21, 1931 | Feb. 28, 1931 | Average | Per acre | |
| *Per cent* | *Pounds* | *Pounds* | *Pounds* | *Pounds* | *Pounds* | *Pounds* | *Pounds* |
| 0 | 0.037 | ---------- | 0.087 | 0.038 | 0.054 | 117.6 | 651 |
| 1 | .090 | 0.429 | .287 | .265 | .267 | 581.5 | 211 |
| 2 | .103 | .275 | .185 | .160 | .180 | 392.0 | 367 |
| 4 | *.238 | .166 | .171 | .559 | .283 | 616.4 | 253 |
| 6 | .587 | .260 | .722 | ---------- | .523 | 1,139.1 | 137 |
| 8 | 1.269 | 1.002 | 1.259 | ---------- | 1.176 | 2,561.3 | 65 |
| 10 | 1.289 | 3.064 | 1.751 | 2.502 | 2.151 | 4,684.6 | 36 |
| 15 | ---------- | ---------- | ---------- | 3.591 | 3.591 | 7,821.2 | 24 |
| 20 | ---------- | ---------- | ---------- | 5.563 | 5.566 | 12,122.7 | 16 |

* 4.16 per cent slope.

TABLE 3.—*Soil eroded and run-off from sandy loam in greenhouse tank at different percentages of slope, November 2, 1931*

[Water applied=1 inch in one hour]

| Slope | Soil eroded— | | Run-off water | | Run-off required to remove 1 pound of soil |
|---|---|---|---|---|---|
| | Per plot | Per acre | | | |
| *Per cent* | *Pounds* | *Pounds* | *Pounds* | *Per cent* | *Pounds* |
| 0.5 | 0.0897 | 195.4 | 71.09 | 68.36 | 792.5 |
| 2.0 | .0519 | 113.1 | 73.62 | 70.80 | 1,417.4 |
| 4.0 | .0880 | 191.6 | 78.74 | 75.73 | 895.1 |
| 8.0 | .4559 | 993.0 | 81.53 | 78.41 | 178.8 |
| 16.0 | 11.559 | 25,175.5 | 81.74 | 78.61 | 7.07 |

TABLE 4.—*Soil eroded and run-off from sandy loam in greenhouse tank at different percentages of slope, November 7, 1931*

[Water applied=1 inch in 30 minutes]

| Slope | Soil eroded— | | Run-off water | | Run-off required to remove 1 pound of soil |
|---|---|---|---|---|---|
| | Per plot | Per acre | | | |
| *Per cent* | *Pounds* | *Pounds* | *Pounds* | *Per cent* | *Pounds* |
| 0.5 | 0.1643 | 357.8 | 86.11 | 82.81 | 524.1 |
| 2.0 | .2138 | 465.7 | 93.08 | 89.52 | 435.3 |
| 4.0 | .3551 | 773.4 | 93.78 | 90.19 | 264.1 |
| 8.0 | 2.573 | 5,604.0 | 95.59 | 91.93 | 37.2 |
| 16.0 | 26.44 | 57,586.3 | 95.54 | 91.88 | 3.6 |

It may be seen from the results that the loss of soil was very low up to a 4 per cent slope. Even with the 8 per cent slope only a relatively small amount was lost when the water was applied at the rate of 1 inch an hour. When the slope was doubled to 16 per cent, the erosion was increased to 25.3 times the amount eroded at 8 per cent. With the heavier applications of water the erosion on the 8 per cent slope was increased to 5.6 times the amount of erosion from the lighter application. When the slope was increased to 16 per cent and water applied at the rate of 1 inch in 30 minutes, the erosion was increased to 10.28 times that on the 8 per cent slope. With an application of 1 inch of water an hour on 16 per cent grade the loss was equivalent to 12.5 tons an acre, and with an application of 1 inch in 30 minutes the loss of soil was equivalent to 28.8 tons an acre.

The run-off from this soil was high and did not show as much variation in amount as in previous tests, but did show the same general type of curve as has been found in both tank and field tests.

## FIELD DETERMINATIONS

### Run-off from Silty Clay Loam

The field determinations were obtained from a plot 34.85 inches wide and 25 feet long or one six-hundredth acre. The soil used was a heavy silty clay loam with a silty clay subsurface. This grades into a heavy clay at 12 to 14 inches. The slope was varied from 0.96 to 5.96 per cent, which was as steep as could be obtained on this land. (Table 5.) The results show the same trend as did the results from the tank, but there was possible a variation of only about 6 per cent in the slope. It may be seen here as in the results from the tank that there is a very great increase in the run-off up to about 2 to 3 per cent. After this, the increase in run-off with increase in slope is much slower.

Table 5.—*Soil eroded from a 1/600-acre plot of silty clay loam on the agronomy farm as related to rate of water application, percentage of slope, and run-off, 1931*

| Date | Rate of water application [a] | Slope | Run-off water | | Soil eroded | Soil eroded per acre | Run-off required to remove 1 pound of soil |
|---|---|---|---|---|---|---|---|
| | | *Per cent* | *Pounds* | *Per cent* | *Pounds* | *Pounds* | *Pounds* |
| June 18 | 1 inch in 30 minutes | 0.96 | 1.986 | 0.53 | 0.0142 | 8.51 | 139 |
| | 1 inch in 1 hour | | 14.875 | 3.94 | .0246 | 14.75 | 604 |
| | (1) 1 inch in 30 minutes | | 174.111 | 46.14 | .4889 | 293.11 | 356 |
| | (2) 1 inch in 30 minutes | | 189.656 | 50.26 | .4445 | 266.5 | 426 |
| | 1 inch in 30 minutes | 2.12 | 35.045 | 9.29 | .1544 | 92.57 | 226 |
| | 1 inch in 1 hour | | 86.900 | 23.03 | .2997 | 179.69 | 289 |
| | (1) 1 inch in 30 minutes | | 238.966 | 63.32 | .6337 | 379.93 | 377 |
| | (2) 1 inch in 30 minutes | | 237.697 | 62.99 | .5026 | 301.33 | 472 |
| June 17 | 1 inch in 30 minutes | 3.8 | 69.564 | 18.43 | .5352 | 320.94 | 129 |
| | 1 inch in 1 hour | | 120.852 | 32.03 | .4472 | 268.12 | 270 |
| | (1) 1 inch in 30 minutes | | 248.646 | 65.89 | .9540 | 571.97 | 260 |
| | (2) 1 inch in 30 minutes | | 267.006 | 70.75 | .7940 | 476.04 | 336 |
| | 1 inch in 30 minutes | 5.96 | 77.616 | 20.57 | .4838 | 290.06 | 160 |
| | 1 inch in 1 hour | | 128.794 | 34.13 | .7054 | 422.92 | 182 |
| | (1) 1 inch in 30 minutes | | 249.152 | 66.02 | 1.2477 | 748.06 | 199 |
| | (2) 1 inch in 30 minutes | | 257.735 | 68.30 | 1.3647 | 818.20 | 188 |

[a] Numbers in parentheses indicate different runs, No. 2 followed immediately after No. 1, which gave an application of 2 inches in 1 hour.

A comparison of the data for different rates of application will show that there is a much greater run-off when water is applied

equivalent to heavier rainfall. This difference is due mainly to the fact that the absorption of water during a water application equivalent to 1 inch an hour is approximately the same as at a 2-inch-an-hour rate.

### Erosion on Silty Clay Loam

The amounts of soil lost from the plots used in these tests were in some instances not so consistent, especially with the lighter applications of water, as the results from a number of other determinations. There were a few cases in which the amount of eroded soil did not fall at the expected place on the curve. The reason for these slight irregularities seems to be due to the fact that it is usually more difficult to get consistent results with the lower slopes and lighter rainfall because slight variations in the surface have a relatively greater effect than on the steep slopes or with heavy rainfall. The general trend of the results with heavier water applications on this soil, however, were similar to those obtained for the same slopes in the other tests.

### Run-off from Sandy Loam

A sandy soil with a sandy subsoil located north of St. George, Kans., 9 miles east of Manhattan, was used for additional tests. The maximum slope here was nearly 12 per cent. At the time these tests were made the soil was extremely dry and no run-off was obtained on the more gentle slopes until about 2 inches of water had been added. (Table 6.) These results followed very much the same trend as those obtained with the tank and with the soil on the agronomy farm. With a 2-inch application of water in 30 minutes after 3 inches had been applied, the increase in run-off was more rapid with the first increase in slope. The run-off from the steeper slopes in this case dropped below that of the intermediate slopes. (Table 6.) No satisfactory explanation can be given for this departure from the regular trend of this curve, but it was probably due to slight irregularities in this sandy soil on the 2 and 4 per cent slopes.

Table 6.—*Soil eroded from a 1/600-acre plot of sandy loam as related to rate of water application, percentage of slope, and run-off, St. George, Kans., July 16–17, 1931*

| Rate of water application | Slope | Run-off water | | Soil eroded | Soil eroded per acre | Run-off required to remove 1 pound of soil |
|---|---|---|---|---|---|---|
| | *Per cent* | *Pounds* | *Per cent* | *Pounds* | *Pounds* | *Pounds* |
| 1 inch in 30 minutes | 0.6 | (a) | (a) | (a) | (a) | |
| 1 inch in 1 hour | | (a) | (a) | (a) | (a) | |
| 1 inch in 30 minutes | | 0.799 | 0.21 | 0.0088 | 5.27 | 91 |
| 2 inches in 30 minutes | | 179.50 | 23.78 | .2743 | 164.4 | 654 |
| 1 inch in 30 minutes | 2.2 | (a) | (a) | (a) | (a) | |
| 1 inch in 1 hour | | (a) | (a) | (a) | (a) | |
| 1 inch in 30 minutes | | 52.83 | 14.00 | .0746 | 44.76 | 708 |
| 2 inches in 30 minutes | | 438.05 | 58.04 | .4547 | 272.8 | 963 |
| 1 inch in 30 minutes | 4.08 | | (a) | | | |
| 1 inch in 1 hour | | | (a) | | | |
| 1 inch in 30 minutes | | 68.43 | 18.13 | .2670 | 160.07 | 256 |
| 2 inches in 30 minutes | | 457.54 | 60.49 | 3.3664 | 2,018.3 | 136 |
| 1 inch in 30 minutes | 7.72 | 1.18 | .31 | .0192 | 11.5 | 61 |
| 1 inch in 1 hour | | 2.27 | .60 | .0227 | 13.6 | 100 |
| 1 inch in 30 minutes | | 56.82 | 15.06 | .5819 | 348.9 | 98 |
| 2 inches in 30 minutes | | 359.72 | 47.67 | 7.1769 | 4,302.9 | 50 |
| 1 inch in 30 minutes | 11.36 | 2.80 | .74 | .2943 | 176.4 | 10 |
| 1 inch in 1 hour | | 8.12 | 2.15 | .3702 | 221.9 | 22 |
| 1 inch in 30 minutes | | 77.68 | 20.59 | 3.9212 | 2,291.0 | 20 |
| 2 inches in 30 minutes | | 355.82 | 47.14 | 28.881 | 17,315.6 | 12 |

[a] None.

### Erosion on Sandy Loam

The soil eroded from the plots when water was applied heavily is represented in the curve in Figure 5. The type of curve obtained on these field plots is very similar to that obtained with the tank and with the silt loam soil. There is a very slow and gradual rise in the amount of erosion up to about 3 to 4 per cent slope, when the curve rises rapidly and erosion becomes exceedingly severe with very rapid rise in the curve at about 7 per cent slope and greater. A 2-inch rain falling in a 30-minute period caused seven times as much erosion on this soil on the steeper slopes and about thirty times as much on the gentle slopes as a 1-inch rain falling in the same time. This difference is due partly to the fact that sand grains are difficult to move, but when sufficient water is running over the surface they are picked up readily and carried down the slope.

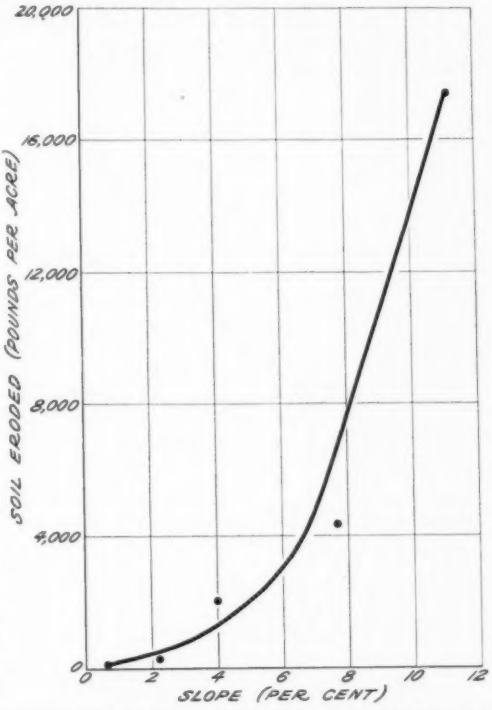



FIGURE 5.—Relation between the degree of slope and the quantity of soil eroded from a sandy loam soil to which water was applied at the rate of 2 inches in 30 minutes after 3 inches had been applied

### SOIL EROSIVENESS

By comparing the amount of erosion shown in Table 2 with that in Table 3 it will be seen that there are some striking differences in the rate of erosion for silty clay loam and sandy loam soils. For the lower slopes, 2 to 8 per cent, there is a much higher erosion from the silty clay loam soil. The 8 per cent slope on the silty clay loam soil gave 158 per cent increase over the amount eroded from the sandy soil, whereas the 16 per cent slope on the sandy soil gave an increase of 222 per cent over the amount lost from the 15 per cent slope on the silty clay loam soil. Thus the relative erosiveness of the two soils was completely reversed simply by changing the slope of the land.

These figures show the difficulty of classing some soils as erosive and others as nonerosive on the basis of certain physical constants as has been attempted by Middleton.[5] It would appear from these

[5] MIDDLETON, H. E. PROPERTIES OF SOILS WHICH INFLUENCE SOIL EROSION. U. S. Dept. Agr. Tech. Bul. 178, 16 p. 1930.

data that erosiveness is not merely a specific property of the soil itself, but the conditions under which the erosion takes place must also be given consideration. Middleton found in the soils with which he worked that the nonerosive soils were low in sand and high in colloids. In the work herein reported, the relative erosiveness of a sandy soil has been found to depend largely on the degree of slope and the rate of rainfall.

In comparing the silty clay loam with the sandy soil it will be seen that with the lower slopes the light soil grains may be carried away from the silt loam, when there is not sufficient speed to the water to pick up the soil particles in the sandy soil. With increase in the slope to 16 per cent the water flows with enough force to carry the larger and heavier particles from the sandy soil; consequently the erosion is greatly increased and far surpasses that from the silty clay loam soil.

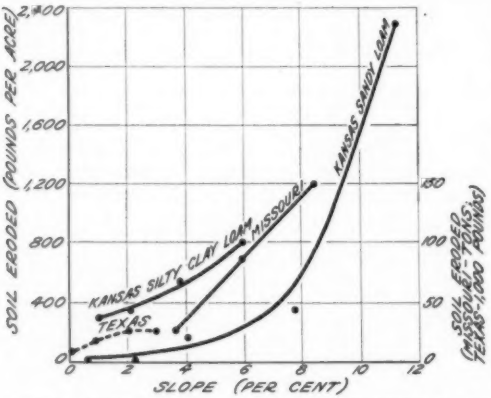



FIGURE 6.—Comparison between soil-erosion results obtained in Kansas with artificial watering and those obtained as annual averages at Columbia, Mo., and Spur, Tex., under natural conditions and on larger plots

The amount of water required to remove 1 pound of soil on the 8 per cent slope was 65 pounds for the silty clay loam and 179 for the sandy loam, but on the 15 per cent slope on the silty clay loam it required 24 pounds, and on the 16 per cent slope on the sandy soil only 7 pounds of run-off water were required to remove 1 pound of soil.

It would therefore seem necessary to take into consideration the degree of slope, the rate of rainfall, and possibly other factors before the relative erosiveness of two soils can properly be expressed.

## APPLICATION OF RESULTS

The question naturally arises as to whether the results obtained by these methods on small plots with water applied artificially, can be applied to field conditions. Some comparisons have been made with results from other stations. In Figure 6 will be found a curve showing results from the Missouri station at Columbia reported by Miller.[6] These results give almost a straight-line curve, but this follows the general direction of the curve for the sandy loam soil used in these tests for the same degree of slope. When differences in location and methods are considered, this probably could be regarded as a reasonably good agreement. Since in the Missouri tests only three points on the curve are represented, it is impossible to show the trend for a wide range of slope since it has been found in the present work with small plots that the greatest increase in erosion is

[6] MILLER, M. F. Op. cit.

to be found at about the point of the lowest slope used in the Missouri tests. A similar comparison was attempted with the results obtained by Conner, Dickson, and Scoates [7] at the Spur, Tex., station. Their results were obtained on slopes ranging from 0 to 3 per cent. This was below the point of greatest increase found in the tests herein reported. The chief difference in the results is the fact that in Texas a large increase in erosion was obtained with the 1 per cent slope as compared with the zero slope. The increase from 1 to 3 per cent slope was much less marked. Another difference in methods is that the different slopes in Texas were produced by artificially adjusting some of the slopes for the entire length of the plot, whereas in the present work the natural slope was used for the length of the plot and the only adjustment of the surface was in leveling across the plot, which in most cases did not disturb much soil.

The amount of run-off obtained in the Texas experiments is represented by the curve *b* in Figure 3. This curve is very similar to that obtained with the tank, except that the 3 per cent slope has given less run-off than has the 2 per cent slope. Conner and his coworkers state that this is probably due to the building up of the soil to obtain the 3 per cent grade.

It would seem from these few comparisons at least, that the methods herein reported give results comparable with those obtained on larger plots and conducted under conditions of natural rainfall. They have the distinct advantage of affording opportunity for a large number of repetitions of comparable conditions as well as the possibility of studying a great number of different conditions bearing on a given problem, and in addition to this may be used for a wide variety of problems. Permanent plots placed at different angles on a hillside could be used to excellent advantage for determining the effect of slope under normal rainfall conditions extending over a long period.

## SUMMARY

Determinations of run-off and erosion were made by means of water applied to soil artificially to simulate rainfall.

In one case a tank, which could be tilted so as to vary the degree of slope of the surface, was filled with soil and used to study the effect of slope on run-off and erosion.

In another test the plots were placed at different angles on a hillside so that the slope ranged from level to that of the steepest part of the hill. By properly locating the plots large variations in soil profile could be avoided.

The results from the two methods checked very well and indicate that the one to be used will depend on the type of problem to be studied.

The run-off was found to increase rapidly as the slope increased from zero to about 3 per cent grade. The increase in run-off was then very slight for each per cent of increase in slope.

The soil eroded increased very gradually until the slope was about 4 per cent, then the increase was found to be more rapid up to about 7 or 8 per cent, after which there was a still greater increase in the rate at which the soil was removed from the plots.

[7] CONNER, A. B., DICKSON, R. E., and SCOATES, D. FACTORS INFLUENCING RUNOFF AND SOIL EROSION. Tex. Agr. Expt. Sta. Bul. 411, 50 p., illus. 1930.

The amount of run-off water required to erode 1 pound of soil decreased rapidly as the slope increased from 1 per cent up to about 10 per cent, after which the decrease was gradual and slight. In some cases the water required to erode 1 pound of soil was less for the 0 and 1 per cent slopes than for a 2 per cent slope.

Soil erosiveness is shown to depend not merely on the physical properties of the soil, but also on the degree of slope and possibly on several other factors. A silty clay loam gave greater erosion on the lower slopes whereas a sandy soil gave more erosion than did the silty clay loam on steep slopes.

The results obtained on large plots in Missouri and Texas have been shown to correspond reasonably well with the results obtained in these tests. This would tend to indicate that small plots having water applied artificially may be used for studying a large number of problems in connection with soil erosion.

# DETERIORATION IN SHELLED GREEN PEAS HELD A FEW DAYS IN STORAGE PRIOR TO CANNING[1]

By Z. I. KERTESZ, *Associate in Research*, and E. L. GREEN, formerly *Associate in Research, Department of Chemistry, New York State Agricultural Experiment Station*[2]

## INTRODUCTION

It is the task of the canners to preserve the flavor and texture of fresh green peas as far as possible. The success or failure of their efforts is mostly decided before the operations within the cannery start, that is to say, by the quality of the harvested peas and by the events and the lapse of time between the cutting of the vines and the actual canning process. To postpone harvesting a given field for a day or so would damage the quality of the canned product, and every delay in the regular progress of the harvested peas to the cannery inevitably means some loss of flavor of the canned peas. Such delays lead to deplorable congestion at the cannery on certain days. It has occurred to a number of workers that peas might be held in cold storage, but the conditions to be met are still to be determined. It is believed that this can be done only after a better understanding of the biochemical reactions that are involved.

The results of a preliminary experiment on holding peas are presented in this paper. This trial was planned as a further step in the study of the reactions in cannery peas which were chosen as the first subject of biochemical investigations on vegetables started at this station in 1929.

The changes that occur in peas that have been removed from the pods are unexpectedly rapid and complex. In a previous study of these changes, the senior writer (*5*)[3] found that an hour at room temperature (25° C.) produces a considerable alteration not only in flavor, but also in chemical composition.

The research department of the American Can Co. has made very extensive trials in holding shelled peas. The experiments showed that slow cooling did not check the objectionable changes before excessive damage had been done to the quality of the peas and that rapid cooling always imparted a sharp flavor. Trials by other investigators on rapid cooling, however, failed to confirm the occurrence of the sharp flavor.

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[3] Reference is made by number (italic) to Literature Cited, p. 370.

In an account of the work done by the research department of the National Canners' Association, Smith (7) reported that he was unable to find any sharp taste in pea samples cooled and held in cold storage. He states that the greatest change in flavor takes place in the first six hours of storage. Afterwards the loss of flavor in cold storage is very slow.

On account of these experiments by Smith it was believed that another experiment on rapid cooling was warranted. The object in making similar experiments was to study the changes in the chemical composition of the peas during storage and to compare these findings with the opinions of competent judges who scored the canned peas. It was of interest, in addition, to study the formation of the sharp taste, which certainly should be associated with detectable changes in the chemical composition of the peas.

## EXPERIMENTAL METHODS

In this preliminary work three different treatments were used, viz, holding peas at room temperature without treatment (series O), cooling and storing the peas at 30° F. without blanching (series C), and cooling and storing at 30°, after blanching (series B).

The peas were collected on July 7, 1931, at Waterloo, N. Y. At this place the viner is located at the factory and not several miles away as is often the case, hence the samples for control analyses could be taken immediately after vining and grading. About a thousand pounds of shelled Perfection peas taken from a single lot were mixed and run through a washer and grader. From these, 450 pounds of size 4 peas were taken for the experiment. The grading was done on a grader with additional washing. This operation precluded any possibility of damaging the quality of the peas by the presence of the so-called viner mucus, which might cause deterioration of the quality of the canned product (*3*).

The washed and graded peas were distributed, without sending them over the picking tables, into pea pails or buckets of galvanized sheet iron with numerous perforations, at the rate of about 20 pounds (9 kg) per pail. The peas in three of these pails received no cooling, those in eight pails were chilled at once, and the remainder were put through the blancher. In the blancher the peas were heated in water to 180° F. (82° C.) for five minutes. They were then cooled with tap water at 68° F. (20° C.) and chilled.

Chilling was done by placing the pails in a wooden tank containing water to a depth of some 30 cm and a considerable quantity of chopped ice, with a temperature of 39° F. (4° C.). The pails were lifted so as to drain a little and were resubmerged several times. In three minutes they reached a temperature of 43° F. (6° C.) as shown by a thermometer thrust into the peas. Equilibrium with the water temperature was attained within five minutes. As soon as the last of the blanched samples was thoroughly chilled, all were removed, covered with chopped ice, and transported by motor truck to a cold-storage warehouse at Geneva, N. Y. The samples were in the cold-storage warehouse within three hours after the arrival of the vines at the vining machine and within little more than one hour after the beginning of the vining.

At the cold-storage warehouse the pails were placed on the floor of a large room held at 30° F. (−1° C.). The temperature in the center of the pails was 38° to 40° F. (3° to 4° C.) when they were put in the cold-storage room. In two hours the temperature of the peas fell to 35° to 38° F. (2° to 3° C.), showing that the usual heating of peas in the pails (*4*) had been entirely avoided by the cooling and by the transportation under ice.

Samples for chemical analysis were taken after grading and washing, but before cooling. Other samples were taken from the blanched peas immediately after leaving the blancher. A canning test for control was made at once after the blanching. The cans were closed and processed as described later.

During their stay in the cold storage, no attempt was made to stir the peas or to prevent or remove the accumulated moisture. At various intervals a pail of each lot was withdrawn and the contents canned. The peas stored at outside air temperature were hot and slimy at the end of 30 hours, so only 2 cannings, 1 at 6 hours and 1 at 20 hours, could be made from these.

For a canning test the peas that had not been heated before storage (the O and C series) were blanched in water at 180° F. (82° C.) for five minutes. The previously blanched or B series were slightly warmed by flushing with tap water at about 63° F. (17° C.). The peas were then weighed at the rate of 10.5 ounces (298 g) to each can (83 mm diameter by 72 mm high inside). Hot brine containing 15 pounds of salt and 30 pounds of sugar per 132 gallons of water was poured in from the regular filling machines, which were operating at the same time, until the cans were full, and the temperature (closing temperature) of several cans was noted. The cans were then closed by regular high-speed closing machines. The cans were processed at 244° F. (118° C.) for 35 minutes and cooled in the usual way in a cold-water cooling tank for about 35 minutes at 75° to 90° F. (24° to 32° C.). The cans were stored for about two months at the experiment station at room temperature, until they were shipped to the different places to be judged and scored.

Samples for chemical analysis were taken before each canning test. The samples were preserved by boiling for 30 minutes in 80 per cent alcohol solution. In general, the methods of the Association of Official Agricultural Chemists were used (*1*). Exceptions to this were that sugars were determined by Bertrand's method (*2*) and that moisture determinations were made by drying a portion of whole peas for 48 hours at 100° C.

## RESULTS OF SCORINGS OF THE CANNED PEA SAMPLES

Samples of the canned peas were submitted to the Washington office of the National Canners' Association; to the Division of Fruits and Vegetables, Bureau of Agricultural Economics, United States Department of Agriculture; to the Wisconsin Department of Markets; to Strasburger and Siegel, consulting chemists; and to a group of members of the agricultural committee of the Association of New York State Canners. Numerical scorings made according to the scoring sheets adopted by the United States Department of Agriculture were obtained from all except the National Canners' Association. The scores are presented in Table 1.

TABLE 1.—*Scoring of canned peas which underwent various treatments before canning*

| Sample No. | Code | Treatment | Storage | Scoring by agencies indicated [a] for— Clearness of liquor (15 points) | | | | Absence of defects (15 points) | | | | Uniformity of size (10 points) | | | | Tenderness and maturity (35 points) | | | | Flavor (25 points) | | | | Total score (100 points) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | Average | Grade [b] |
| | | | *Hours* | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1 | ------ | None (control) | ------ | 13 | 13 | 13 | 14 | 13 | 13 | 13 | 13 | 8 | 9 | 7 | 8 | 29 | 32 | 31 | 30 | 21 | 21 | 21 | 21 | 84 | 88 | 85 | 86 | ------ | ------ |
| 2 | ------ | | ------ | ---- | ---- | 13 | ---- | ---- | ---- | 13 | ---- | ---- | ---- | 7 | ---- | ---- | ---- | 31 | ---- | ---- | ---- | 21 | ---- | ---- | ---- | ---- | 85 | 86 | B |
| 3 | POA | | 6 | 11 | 8 | 12 | 14 | 14 | 13 | 13 | 14 | 8 | 9 | 7 | 8 | 25 | 27 | 27 | 29 | 18 | 16 | 18 | 20 | 76 | 73 | 77 | 85 | 78 | C (B) |
| 4 | POB | | 20 | 12 | 8 | 13 | 13 | 12 | 8 | 8 | 8 | 5 | 8 | 5 | 4 | 19 | 24 | 25 | 27 | 14 | 14 | 10 | 16 | 62 | 62 | 61 | [c] 68 | 63 | Sub (C) |
| 5 | PBA | Blanched, cooled in ice water, and stored at 30° F. | 6 | 13 | 12 | 13 | 14 | 14 | 13 | 13 | 14 | 8 | 9 | 7 | 8 | 29 | 31 | 30 | 30 | 19 | 20 | 19 | 21 | 83 | 85 | 82 | 87 | 83 | B |
| 6 | PBB | | 20 | 14 | 11 | 13 | 14 | 13 | 12 | 12 | 14 | 8 | 9 | 7 | 7 | 28 | 29 | 29 | 29 | 17 | 18 | 18 | 19 | 80 | 79 | 79 | 83 | 80 | C (B) |
| 7 | PBC | | 30 | 14 | 12 | 13 | 14 | 13 | 12 | 13 | 14 | 8 | 9 | 7 | 8 | 29 | 27 | 29 | 27 | 19 | 17 | 19 | 19 | 83 | 77 | 81 | 82 | 80 | B (C) |
| 8 | PBD | | 48 | 14 | 12 | 12 | 11 | 13 | 12 | 13 | 14 | 8 | 9 | 7 | 5 | 29 | 25 | 28 | 27 | 17 | 16 | 19 | 18 | 81 | 74 | 79 | 75 | 77 | C (B) |
| 9 | PBE | | 72 | 14 | 12 | 13 | 14 | 13 | 12 | 13 | 14 | 8 | 9 | 7 | 6 | 30 | 27 | 27 | 28 | 18 | 16 | 18 | 19 | 83 | 76 | 78 | 81 | 80 | C (B) |
| 10 | PBF | | 96 | 14 | 12 | 13 | 14 | 14 | 12 | 13 | 10 | 8 | 9 | 7 | 4 | 28 | 24 | 29 | 27 | 17 | 12 | 16 | 17 | 81 | 69 | 77 | 72 | 75 | C (Sub) |
| 11 | PBG | | 144 | 14 | 12 | 12 | 13 | 13 | 12 | 13 | 11 | 8 | 9 | 6 | 5 | 28 | 24 | 27 | 28 | 16 | 12 | 16 | 18 | 79 | 69 | 74 | 75 | 74 | C (Sub) |
| 12 | PBH | | 190 | 14 | ---- | 12 | 12 | 13 | ---- | 13 | 10 | 8 | ---- | 5 | 3 | 30 | ---- | 27 | 26 | 14 | ---- | 16 | 17 | 79 | ---- | 73 | [c] 68 | 73 | C (Sub) |
| 13 | PCA | Cooled in ice water and stored at 30° F.; blanched before canning. | 6 | 12 | 11 | 13 | ---- | 13 | 14 | 13 | ---- | 8 | 9 | 7 | ---- | 28 | 28 | 27 | ---- | 19 | 19 | 17 | ---- | 80 | 81 | 77 | ---- | 79 | B (C) |
| 14 | PCB | | 20 | 14 | 12 | 13 | 14 | 12 | 14 | 13 | 10 | 8 | 9 | 7 | 7 | 28 | 27 | 28 | 27 | 18 | 19 | 17 | 19 | 80 | 81 | 78 | 77 | 79 | C |
| 15 | PCC | | 30 | 14 | 12 | ---- | 14 | 14 | 14 | ---- | 14 | 8 | 9 | ---- | 8 | 26 | 26 | ---- | 27 | 17 | 18 | ---- | 19 | 79 | 79 | ---- | 82 | 80 | C |
| 16 | PCD | | 48 | 14 | 12 | 13 | 11 | 13 | 13 | 12 | 14 | 8 | 9 | 7 | 5 | 27 | 25 | 27 | 27 | 17 | 17 | 17 | 18 | 79 | 76 | 76 | 75 | 76 | C |
| 17 | PCE | | 72 | 14 | 12 | 12 | 14 | 13 | 13 | 12 | 14 | 8 | 9 | 7 | 5 | 26 | 24 | 28 | 27 | 16 | 16 | 17 | 18 | 77 | 74 | 76 | [c] 78 | 77 | C (Sub) |
| 18 | PCF | | 96 | 14 | 11 | 13 | 13 | 11 | 13 | 13 | 14 | 8 | 9 | 7 | 6 | 25 | 24 | 26 | 27 | 15 | 16 | 16 | 18 | 65 | 73 | 75 | [c] 78 | 73 | C (Sub) |
| 19 | PCG | | 144 | 13 | 11 | ---- | 13 | 11 | 11 | ---- | 11 | 7 | 8 | ---- | 5 | 24 | 24 | ---- | 27 | 14 | 14 | ---- | 18 | 62 | 68 | ---- | [c] 74 | 68 | Sub (C) |

[a] 1=the average of 5 experts' scores (Geneva, August, 1931); 2=scores of Strasburger and Siegel; 3=scores of the U. S. Department of Agriculture, Bureau of Agricultural Economics; 4=scores of Wisconsin Department of Markets.

[b] B=extra standard, C=standard, sub=substandard (off=) grade.

[c] Declared to have a peculiar and objectionable flavor by the Washington laboratory of the National Canners' Association.

From the Washington laboratory of the National Canners' Association only descriptive opinions were received, without numerical scoring. As flavor is the most important factor in the present experiment, the opinion of this laboratory about the flavor of the pea samples is quoted as follows:

> The peas in cans PBH and POB had a flavor which we have come to associate with the deterioration of peas which have been held too long between vining and canning. The peas in cans PCE and PCF had a peculiar abnormal and objectionable flavor with which we are not familiar. None of those judges who tasted these peas had ever experienced this particular flavor in connection with canned peas and we were not able to arrive at any reasonable suggestion as to the cause of this poor flavor.

The gradings for the control samples showed an average of 86 points, which placed them in the range of Extra Standard peas. If the control pack had been Fancy, the resulting samples might have deteriorated at a different rate from the present samples.

There was a very rapid decrease in quality in the peas stored at outside temperature. The sample canned 6 hours after vining was scored 78 and declared to be Standard grade. As one would expect, the sample canned 20 hours after vining resulted in a pack of inferior quality, which was scored by all judges as Substandard, with the average score of 63.

When the blanched and cooled samples were taken to the factory for the various canning trials, they were always submitted to the factory manager who was unable to detect any change in the characteristics of the peas. This fact was not surprising, since Smith (*8*) also notes that the real character of the peas becomes apparent only after canning and storing. At the last cannings the peas of the C series (cooled without blanching) appeared to be in the raw state somewhat harder than the corresponding sample from the B series, which was blanched before cooling.

The blanched and cooled sample was found by all judges to be in the extra standard or standard grade after 72 hours' storage. The peas in the cans packed after 96 and 144 hours were found to be substandard by one grader (Strasburger & Siegel), but were rated as standard by the other two. The cans packed after 190 hours of storage were undoubtedly substandard. The code of this sample was PBH, and this was one of the samples mentioned by officials of the National Canners' Association as being "abnormal and objectionable." According to these scorings, one might expect the peas held in cold storage to yield packs of standard or higher grade until the period between 72 and 96 hours, while the definite change from standard to substandard packs probably occurred in the period between 120 and 150 hours after vining.

The peas cooled without blanching appeared to have deteriorated somewhat more rapidly than did those blanched before cooling. The sample canned 48 hours after vining was in the standard grade, while the sample canned 72 hours after vining gave a substandard pack. This was one of the bad-flavored samples, according to the opinion of the laboratory of the National Canners' Association. While the sample canned after being held 72 hours was scored substandard by one judge only, the next sample, canned 96 hours after vining, was declared by two of them to be in this grade. The change from the standard to the substandard grade must have occurred some time between 50 and 100 hours, undoubtedly sooner than that in the blanched and cooled sample.

TABLE 2.—*Changes in the chemical composition of peas during cold storage* [a]

[Figures are percentages on the basis of fresh wet peas]

| Constituent | Percentage content of peas, not blanched before storage, after indicated hours of storage | | | | | | Percentage content of peas, blanched before storage immediately after shelling, after indicated hours of storage | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Controls, not stored [b] | CB, 20 hours | CD, 48 hours | CE, 72 hours | CF, 96 hours | CG, 144 hours | Controls, not stored [b] | BB, 20 hours | BD, 48 hours | BE, 72 hours | BF, 96 hours | BG, 144 hours | BH, 190 hours |
| Dry matter | 23.15 | 22.83 | 21.63 | 21.75 | 22.26 | 20.64 | 22.39 | 21.74 | 21.69 | 22.36 | 21.15 | 21.97 | 20.03 |
| Alcohol-soluble matter | 6.56 | 7.71 | 6.28 | 7.83 | 7.62 | 5.31 | 5.10 | 4.87 | 5.57 | 5.40 | 4.48 | 5.53 | 4.36 |
| Reducing sugars | .37 | .25 | .41 | .05 | .16 | .28 | .26 | .13 | .19 | .03 | .16 | .05 | .54 |
| Sucrose | 3.51 | 2.37 | 2.54 | 2.51 | 2.37 | 1.75 | 2.64 | 2.62 | 2.30 | 2.48 | 2.32 | 2.43 | 2.23 |
| Total sugars | 3.88 | 2.62 | 2.95 | 2.56 | 2.53 | 2.03 | 2.90 | 2.75 | 2.49 | 2.51 | 2.48 | 2.48 | 2.77 |
| Nonprotein nitrogen | .158 | .165 | .155 | .159 | .160 | .166 | .130 | .119 | .104 | .113 | .101 | .105 | .144 |
| Nonprotein nitrogen×6.25 | .986 | 1.034 | .972 | .995 | 1.000 | 1.040 | .813 | .744 | .651 | .707 | .631 | .657 | .903 |
| Unidentified alcohol-soluble matter | 1.70 | 4.06 | 2.36 | 4.27 | 4.09 | 2.24 | 1.39 | 1.38 | 2.43 | 2.18 | 1.37 | 2.39 | .69 |
| Total alcohol-insoluble matter | 16.59 | 15.12 | 15.35 | 13.92 | 14.64 | 15.33 | 17.29 | 16.87 | 16.12 | 16.96 | 16.67 | 16.14 | 15.67 |
| Starch | 3.13 | 2.60 | 2.66 | 2.78 | 2.56 | 2.65 | 3.44 | 3.40 | 2.76 | 3.00 | 2.96 | 3.07 | 2.85 |
| Crude fiber | 1.93 | 1.88 | 1.72 | 1.46 | 1.66 | 1.77 | 1.90 | 1.85 | 1.84 | 1.96 | 2.09 | 1.78 | 1.79 |
| Protein nitrogen | .947 | .865 | .856 | .773 | .822 | .873 | .965 | .899 | .865 | .946 | .893 | .915 | .852 |
| Protein nitrogen×6.25 | 5.92 | 5.41 | 5.35 | 4.83 | 5.14 | 5.46 | 6.03 | 5.62 | 5.41 | 5.91 | 5.58 | 5.72 | 5.333 |
| Unidentified alcohol-insoluble matter | 5.61 | 5.23 | 5.62 | 4.85 | 5.28 | 5.45 | 5.92 | 6.00 | 6.11 | 6.09 | 5.94 | 5.69 | 5.70 |
| Total nitrogen | 1.105 | 1.030 | 1.011 | .932 | .982 | .939 | 1.095 | 1.018 | .969 | 1.058 | .993 | 1.020 | .996 |

[a] Double letters at top of columns are codes of samples.
[b] Averages.

TABLE 3.—*Changes in the chemical constituents of single peas during cold storage* [a]

[Figures are in grams of weight per single pea]

| Constituent | Percentage of content of peas, not blanched before storage, after indicated hours of storage | | | | | | Percentage content of peas, blanched before storage immediately after shelling, after indicated hours of storage | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Controls, not stored [b] | CB, 20 hours | CD, 48 hours | CE, 72 hours | CF, 96 hours | CG, 144 hours | Controls, not stored [b] | BB, 20 hours | BD, 48 hours | BE, 72 hours | BF, 96 hours | BG, 144 hours | BH, 190 hours |
| Total weight | 0.4060 | 0.430 | 0.430 | 0.430 | 0.416 | 0.446 | 0.3731 | 0.404 | 0.394 | 0.396 | 0.383 | 0.384 | 0.389 |
| Dry matter | .0941 | .0982 | .0930 | .0955 | .0928 | .0920 | .0835 | .0874 | .0854 | .0886 | .0812 | .0846 | .0782 |
| Alcohol-soluble matter | .0267 | .0317 | .0257 | .0344 | .0320 | .0238 | .0190 | .0194 | .0218 | .0216 | .0168 | .0214 | .0172 |
| Reducing sugars | .0015 | .00108 | .00176 | .00021 | .00061 | .00125 | .00097 | .00052 | .00075 | .00012 | .00062 | .00019 | .00210 |
| Sucrose | .0143 | .0102 | .0109 | .0111 | .0099 | .0078 | .0099 | .0106 | .0090 | .0098 | .0089 | .0094 | .0087 |
| Total sugars | .0158 | .0113 | .0127 | .0113 | .0105 | .00905 | .01087 | .0111 | .00981 | .0100 | .00953 | .00954 | .0108 |
| Nonprotein nitrogen | .00064 | .000707 | .000666 | .000683 | .000665 | .000742 | .00049 | .000481 | .000410 | .000421 | .000386 | .000404 | .00056 |
| Nonprotein nitrogen×6.25 | .00401 | .00442 | .00416 | .00427 | .00416 | .00464 | .00303 | .00301 | .00258 | .00263 | .00252 | .00252 | .00350 |
| Unidentified alcohol-soluble matter | .00691 | .0160 | .0038 | .0188 | .0173 | .0102 | .00519 | .0053 | .0094 | .0091 | .0049 | .0093 | .0029 |
| Total alcohol-insoluble matter | .0677 | .0665 | .0673 | .0611 | .0608 | .0682 | .0645 | .0680 | .0636 | .0670 | .0644 | .0632 | .0610 |
| Starch | .0127 | .01118 | .01144 | .01195 | .01065 | .01182 | .0128 | .01370 | .01087 | .01188 | .01124 | .01179 | .01109 |
| Crude fiber | .0078 | .00808 | .00740 | .00629 | .00690 | .00789 | .0071 | .00747 | .00725 | .00778 | .00800 | .00684 | .00698 |
| Protein nitrogen | .00385 | .00342 | .00370 | .00334 | .00342 | .00390 | .0036 | .00340 | .00342 | .00374 | .00342 | .00352 | .00332 |
| Protein nitrogen×6.25 | .0241 | .0214 | .0231 | .0209 | .0214 | .0244 | .0225 | .0213 | .0214 | .0234 | .0214 | .0220 | .0208 |
| Unidentified alcohol-insoluble matter | .0228 | .0258 | .0254 | .0220 | .0219 | .0241 | .0221 | .0255 | .0241 | .0239 | .0240 | .0226 | .0221 |
| Total nitrogen | .0045 | .00413 | .00437 | .00402 | .00409 | .00464 | .0041 | .00388 | .00383 | .00416 | .00381 | .00392 | .00388 |

[a] Double letters at top of columns are codes of samples.
[b] Averages.

## RESULTS OF THE CHEMICAL ANALYSES

The samples for chemical analysis were taken immediatly after grading, after blanching, and before every canning test. They were preserved by boiling in alcohol, as mentioned above, and were analyzed after two weeks of storage. The results, calculated on the basis of the fresh weight of the peas when the samples were taken, and on the basis of a single pea, and are presented in Tables 2 and 3. The weight of a single pea was determined by counting 50 g of peas used for a sample.

The dry-matter content of the samples decreased slightly during storage. The weight of a single pea, on the other hand, increased, probably because of the condensation of moisture from the air of the room on the peas. No effort was made to dry the peas before sampling. This accounts for a part of the decrease of the percentage of dry matter, which occurred in the bleached peas. This fact, however, shows the advantages of presenting the data on a single-pea basis, because in this way changes in the actual quantities of the constituents can be traced regardless of the loss or gain of moisture and gases.

There was some decrease in the total sugars in the samples of the unblanched series, the largest decrease being shown during the first 20 hours of the experiment. Blanching reduced the amount of total sugars to the same degree as did storage of the unblanched sample for 20 hours. Total sugars may be consumed by respiration in the unblanched sample and leached out in the other. The decrease in the percentage of sucrose and of the total sugars is much less than the loss of the latter constituent in peas kept at room temperature, for which the senior writer (*5*) showed as much as 52 per cent decrease in total sugar and starch content during the first 24 hours. The losses in the total sugars of the unblanched samples were roughly 30 per cent, and were possibly related to a small, but definite loss of flavor, namely 3 points of a possible 25. The only significance to be attached to this fact is that it indicates a certain enzymic and respiratory activity that is undoubtedly related to the more rapid deterioration of the unblanched samples.

In storage there was practically no decrease in the total sugars in the blanched samples, showing that heating for five minutes to 180° F. (82° C.) had mostly inactivated the saccharose and the respiratory enzymes.

Only immaterial changes could be found in the starch content of the peas. This shows that even in the unblanched sample amylase activity was unimportant. This enzyme was shown by Kertesz (*5*) to be very active in macerated peas at room temperature. Likewise, the crude-fiber content of the samples did not show any greater variation than may be regarded as due to sampling and experimental error.

The nitrogen compounds were separated into 80 per cent alcohol-soluble and 80 per cent alcohol-insoluble fractions. For the sake of comparison they were calculated as proteins (nitrogen $\times$ 6.25). This was also necessary in the subtraction made to determine the unidentified fraction, since the actual weight of nonprotein nitrogen compounds is certainly nearer to nitrogen $\times$ 6.25 than to the actual weight of nitrogen found. It must be understood, however, that the 80 per cent alcohol-soluble nitrogen fraction should be regarded as being composed mostly of nonprotein nitrogen compounds. Changes

in both fractions of nitrogen in the samples as analyzed were small and not greater than the experimental error.

None of the constituents determined directly appeared to fluctuate in conformity with the observed changes in quality.

## DISCUSSION

The most obvious conclusion to be drawn from the present experiment is that deterioration in flavor is a more important consideration in holding shelled peas in storage before canning than texture, or the variation of the more obvious of the chemical constituents. The changes in texture, or the increase in toughness, which have been given so much emphasis recently, have a relatively minor effect on the total score and do not occur until much later than the loss of flavor.

It is also obvious that in the present investigation the changes in the flavor of peas held after vining can not be explained by reciprocal conversions of sugar and starch. The statement that sugar is changed to starch during holding is often encountered in the trade literature concerning peas, but in this experiment no evidence of such a change was found. This should not appear startling, for the flavor of the peas is judged after canning in a solution containing sucrose. Furthermore it has been found that the addition of the indicated sugar does not make the flavor of lower-grade peas equal to that of choice peas. In the unblanched samples, where the enzymes had not been inactivated, there was a slight decrease in the absolute amount of starch (single pea basis), together with some loss in the total sugars as well. It is suggested that respiration accounts for this loss of starch and sugar.

It is reasonable to suppose that the respiration in the unblanched samples was not entirely stopped by cooling, and this would account for the more rapid deterioration of these peas. Table 1 shows that the blanched peas held for more than 72 hours were always scored higher than were the unblanched. The small extent of the changes in the constituents determined chemically is in sharp contrast with the great extent of the changes in the flavor.

The changes observed in the amounts of the two nitrogen fractions are insignificant. An alteration in the proportions of the alcohol-soluble and the alcohol-insoluble fractions during storage was expected, but only immaterial changes could be found. It was supposed that the sharp flavor often encountered in peas held too long after vining might be accounted for by some such change. No sharp flavor was developed in these samples, and therefore this hypothesis could not be tested.

The question still remains, why did not the combination of blanching and cooling prevent the deterioration of the peas? Two suggestions are offered as possible answers. One is that the changes in the peas held in cold storage may be caused by direct oxidation by the oxygen of the air, independently of respiration or other enzyme actions. These changes could then possibly be eliminated by storing the peas in nitrogen or carbon dioxide. Because of the very short season for obtaining material this supposition could not be tested this year. The second suggestion follows from the fact that, as Kertesz (*5*) has shown, all the chemical changes proceed more rapidly

in macerated peas than in the normal whole peas. It is well known that the rate of respiration increases in bruised or injured plant tissues. When peas are shelled by machine in the usual way, and then separated into sizes over rolling or vibrating metal screens a greater or less amount of bruising is inevitable. This bruising is equivalent in its effect to a certain amount of maceration, and such peas have been shown by Sayre, Willaman, and Kertesz (*6*) to deteriorate more rapidly than do hand-shelled peas. The changes in the machine-shelled peas proceed with extreme rapidity so that they become far advanced during the short interval between shelling and cooling. These changes may then be retarded or stopped altogether by blanching or cooling, but they are already extensive enough to produce a decidedly deleterious effect on the flavor. Apparently, blanching will stop these changes better than does cooling alone. The condition reached after blanching is then maintained for a longer period than that of peas simply chilled, where respiration is probably at a higher rate.

## SUMMARY

Peas were kept in cold storage for several days without deterioration when chilled quickly to the storage temperature (30° F.). Deterioration was slower in peas blanched before cooling than in peas cooled and stored at 30° without blanching.

During storage the percentage and absolute amount of total sugars in the unblanched, chilled sample decreased, showing respiratory activity. In the blanched and chilled peas there was no loss in sugars, showing that the respiratory enzymes were mostly inactivated by heating the peas for five minutes to 180° F.

The percentage and absolute amount of starch per pea did not increase in shelled and stored peas, showing that there was no conversion of sugars to starch.

None of the chemical constituents determined appeared to fluctuate in conformity with the observed changes in quality.

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# LIFE HISTORY AND HABITS OF CRESTED WHEATGRASS [1]

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## INTRODUCTION

Crested wheatgrass, *Agropyron cristatum* J. Gaertn., has recently become important as a pasture and hay plant in the northern part of the Great Plains as well as in the Rocky Mountain region. It is especially valuable because it begins to grow a week or two earlier than other grasses in the spring. It is an upright perennial bunch grass and is well adapted to many of the lighter soils in the semiarid regions.

L. E. Kirk,[3] in a bulletin recently published, has described the characteristics of crested wheatgrass that adapt it to cold and drought. He has shown that it is successful in controlling weeds, and he has discussed its uses as hay and pasture and as turf for lawns and golf courses.

## THE SEED

The seed is light yellow in color, wide and blunt at the base, and has a short awn. The lemma and palea are prominently rolled. The back and sides of the lemma contain several well-spaced spines toward the tip. (Fig. 1.) The rachilla is not appressed to the lemma and palea. *Agropyron cristatum* is easily distinguished from both *A. tenerum* Vasey and *A. smithii* Rydb. by its smaller size and rolled shape.

The rachilla segment (fig. 2) of *Agropyron cristatum* has a wide blunt base and U-shaped sinus, the lemma edges at the callus not obscuring the almost parallel sides of the rachilla. The apex of the rachilla is oblong and the segment itself is characterized by prominent stout hairs.

The palea is hirsute over the entire surface. The hairs on the edge of the palea are short, stout, somewhat pointed and spaced farther apart than those of *Agropyron tenerum* or *A. smithii*.

*Key for Identification of Four Species of Agropyron*

Rachilla cone-shaped, arising from a V-shaped sinus; apex elliptical.
- Rachilla segment hirsute. Palea hirsute over entire surface; hairs on edges stout and fairly long ---- *Agropyron smithii*
- Rachilla segment pilose. Palea puberulent at tip; hairs on edges fine, acute, and close together ---- *Agropyron tenerum*

Rachilla cylindrical in shape, arising from a U-shaped sinus; apex oval to oblong.
- Apex of rachilla segment heart-shaped; segment hispidulous. Palea puberulent at tip; hairs on edges short, stout, and blunt ---- *Agropyron repens*
- Apex of rachilla segment oblong; segment sparsely hispid. Palea hirsute over entire surface; hairs on edges short, stout, somewhat pointed, and spaced fairly far apart ---- *Agropyron cristatum*

[1] Received for publication Jan. 13, 1932; issued October, 1932.
[2] The authors are indebted to Prof. O. A. Stevens for the facilities necessary to make the germination tests and to J. T. Sarvis, Leroy Moomaw, and Samuel Garver for supplying seed.
[3] KIRK, L. E. CRESTED WHEAT GRASS. Saskatchewan University Agr. Ext. Bul. 54, 22 p., illus. 1932.

In order to determine the length of time that crested wheatgrass seed retains its viability, a series of germination tests were made.

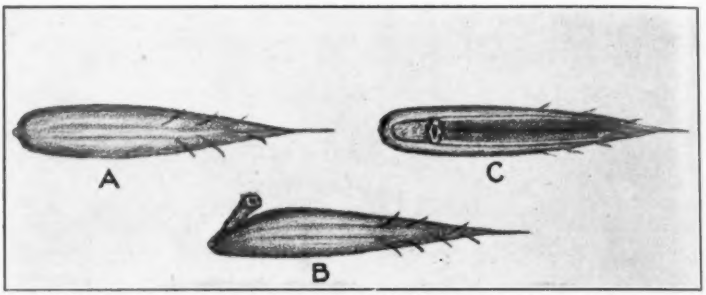


FIGURE 1.—Dorsal (A), lateral (B), and ventral (C) view of the seed of crested wheatgrass

One hundred and fourteen lots of seed grown in various years from 1919 to 1930 were tested. The seed came from Mandan, N. Dak., Dickinson, N. Dak., Redfield, S. Dak., Havre, Mont., and Saskatoon, Canada. Several of the lots were individual plant selections made by J. T. Sarvis or A. C. Dillman. The seed in most cases had been stored in a dry, moderately cool place. Each lot of seed was tested once in the period from October to November, 1930, in accordance with the methods of the official seed analysts. One test was considered sufficient when averaged with other lots of the same year.

FIGURE 2.—Rachilla segment of crested wheatgrass

The number of lots that were tested, and the average percentage of germination are presented in Table 1. This table shows a sharp decline in the percentage of germination of seed harvested prior to 1926. It was noted in the germination tests that the 1930 seed germinated more completely at the end of five days than the 1926 or 1927 seed. This fact suggests that the rate of germination decreases along with the percentage of germination. The data show, then, that crested wheatgrass seed, if stored in a cool, dry place, may be expected to germinate satisfactorily until 4 years of age.

TABLE 1.—*Percentage germination of crested wheatgrass seed of various years*

| Year | Lots | Average germination | Year | Lots | Average germination | Year | Lots | Average germination |
|---|---|---|---|---|---|---|---|---|
| | *Number* | *Per cent* | | *Number* | *Per cent* | | *Number* | *Per cent* |
| 1919 | 10 | 1.0 | 1923 | 22 | 30.6 | 1927 | 2 | 85.5 |
| 1920 | 15 | 5.5 | 1924 | 2 | 32.0 | 1928 | 0 | |
| 1921 | 2 | 0 | 1925 | 4 | 53.0 | 1929 | 2 | 90.0 |
| 1922 | 1 | 4.0 | 1926 | 28 | 86.1 | 1930 | 28 | 91.2 |

## DEVELOPMENT AND MORPHOLOGY OF THE SEEDLING

In its natural state crested wheatgrass seed falls to the ground shortly after maturity and lies there until favorable conditions permit germination. This indicates that the natural time of seeding is in the fall, but tests in some places show that no appreciable difference exists between spring and fall sowing.

During the fall and winter of 1930–31 tests on depth of planting were conducted in the greenhouse. Good tilth of the clay soil was secured in order to have about the same amount of moisture throughout. Two hundred seeds were planted at each of the following depths: One-eighth, one-fourth, one-half, three-fourths, 1, 2, 3, 4, 5, and 6 inches. In the bench where the plantings were made the soil was about 20 inches deep. At the end of 5, 10, and 28 days the seedlings that appeared above the surface were counted. After 28 days the leaf area of all the seedlings was determined by multiplying the average length by the average width in millimeters. The results are given in Table 2.

TABLE 2.—*Effect of various depths of planting on crested wheatgrass seed*

| | Values for depths of seeding (inches) indicated | | | | | | |
|---|---|---|---|---|---|---|---|
| | One-eighth | One-fourth | One-half | Three-fourths | 1 | 2 | 3 |
| Seeds.....number... | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| Plants in 5 days.....do... | 15 | 4 | | | | | |
| Plants in 10 days.....do... | 134 | 140 | 114 | 125 | 93 | 91 | 10 |
| Plants in 28 days.....do... | 139 | 135 | 116 | 130 | 99 | 78 | 19 |
| Average height in 28 days.....inches... | 6.5 | 6.5 | 6 | 6 | 5.3 | 5.5 | 4 |
| Total leaf area.....cm²... | 2,546.2 | 2,353.4 | 2,233.7 | 2,360.8 | 1,540.9 | 1,095.7 | 130.9 |
| Average leaf area per plant.....cm²... | 18.3 | 17.4 | 19.2 | 18.2 | 15.6 | 14.1 | 6.9 |
| Shoots above surface in 10 days.....per cent... | 67.0 | 70.0 | 57.0 | 62.5 | 46.5 | 45.5 | 5.0 |
| Shoots above surface in 28 days.....do.... | 69.5 | 67.5 | 58.0 | 65.0 | 49.5 | 39.0 | 9.5 |

Cm² is the abbreviation for square centimeter recently adopted by the Style Manual for U. S. Government Printing.

The measurements taken at the end of 28 days showed a gradation in height from 6.5 inches for plants from seeds planted at the ⅛-inch depth to 4 inches for plants from seeds planted at the 3-inch depth. The difference in the average leaf area between the seedlings from the one-eighth and the one-half inch depths may have been due partly to competition, since there were fewer seedlings at the one-half inch depth than at the one-fourth or one-eighth inch depths. The maximum depth from which seedlings appeared above the surface was 3 inches. Seed of crested wheatgrass germinates well upon the surface of the soil when there is sufficient moisture, but in the field, where the surface is usually dry, it appears that the best depth at which to plant the seed is between one-fourth and one-half inch, depending upon the dryness of the surface soil.

A similar experiment for bromegrass showed that the maximum depth at which the seed germinated and sent shoots to the surface was 3 inches. At this depth about 5 per cent of the seeds were able to send shoots to the surface. About 65 per cent of the seeds planted at one-eighth to 1 inch produced seedlings above the surface.

In order to study the development of the seedling, seeds were germinated in a damp chamber at a temperature of about 25° C. At

the end of 24 to 48 hours the coleorhiza had formed and several distinct root hairs were already present on it. At the end of 48 to 72 hours, the coleoptile began to appear. The primary root was about twice as long as the coleorhiza and had several root hairs. At 72 to 96 hours, both the coleoptile and primary root were well developed; the latter was about as long as the seed and was covered with a thick mat of root hairs. At 96 to 120 hours, the coleoptile was about as long as the seed and the primary root about twice as long as the seed. (Fig. 3.)

In a similar experiment bromegrass did not develop a shoot until 48 to 72 hours after the seed was placed in a damp chamber. This indicates that, although a little slower in producing the coleoptile, it had good roots to begin shoot growth.

During the winter of 1930–31, greenhouse studies were made of the rate of root and shoot elongation of crested wheatgrass as compared with that of bromegrass. This comparison was made because it had been observed that the seedlings of crested wheatgrass were much more frail and delicate than those of bromegrass.

Examinations were made at the end of 10, 17, 24, 31, and 45 days. The development of the seedlings of both of these grasses is shown in Figure 4. During the first 24 days bromegrass had a distinct advantage over crested wheatgrass in both root and shoot development. Although the main root of bromegrass penetrated somewhat deeper, the branches were fewer. At all stages the height of the shoot in both grasses was approximately the same, but the leaves of bromegrass were wider. Bromegrass therefore had a larger and more vigorous seedling.

TABLE 3.—*Root and shoot development of seedlings of crested wheatgrass and bromegrass at different ages*

| Age intervals (days) | Crested wheatgrass | | | | Bromegrass | | | |
|---|---|---|---|---|---|---|---|---|
| | Average daily growth in height | | Average daily growth | | Average daily growth in height | | Average daily growth | |
| | Shoot | Root | Shoot | Root | Shoot | Root | Shoot | Root |
| | *Inches* | *Inches* | *Per cent* | *Per cent* | *Inches* | *Inches* | *Per cent* | *Per cent* |
| 10 to 17 | 0.357 | 0.107 | 8.92 | 4.28 | 0.286 | 0.250 | 7.14 | 6.66 |
| 17 to 24 | .214 | .143 | 3.89 | 4.08 | .286 | .250 | 4.76 | 4.54 |
| 24 to 31 | .214 | .29 | 3.56 | 5.19 | .143 | .143 | 2.04 | 2.19 |
| 31 to 45 | .214 | .160 | 2.24 | 2.06 | .178 | .178 | 1.87 | 1.97 |

In order to determine whether crested wheatgrass developed more rapidly after a certain period than bromegrass, the following method was devised: The height or length, measured in inches at the end of an interval (i. e., 17 or 24 days, etc.), was divided by the number of days in the interval in order to secure the average daily growth in height. This average daily growth, divided by the average maximum height at the end of the interval, multiplied by 100, gives the average daily height percentage that the plant grew each day during a particular interval. Table 3 shows the root and shoot development of seedlings of crested wheatgrass and bromegrass. From these data it appears that the development of both the root and shoot is more rapid in bromegrass than in crested wheatgrass during the first 24

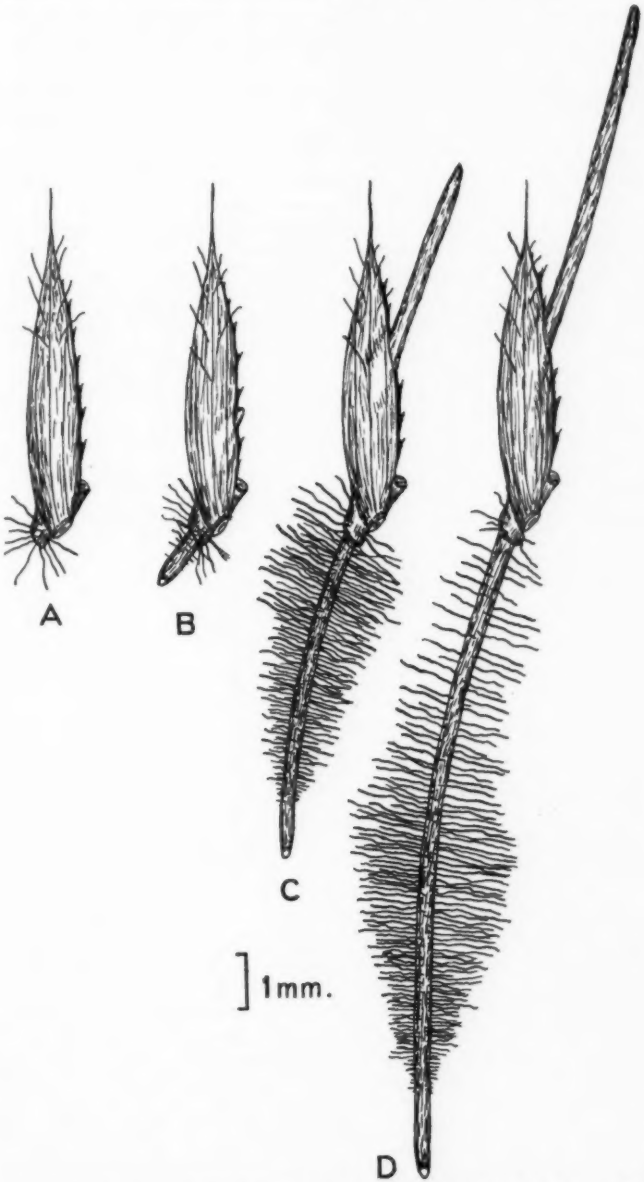


FIGURE 3.—Development of crested wheatgrass seedling: A, When aged 24 to 48 hours; B, 48 to 72 hours; C, 72 to 96 hours; D, 96 to 120 hours

days. From then on to the end of 45 days, the development of the root and shoot of crested wheatgrass is slightly more rapid than that of bromegrass. This is offered as a possible explanation of how crested wheatgrass overcomes the handicap of a very small seedling and develops into one of the most drought resistant of forage plants. This change during the seedling stage has also been noted in the field.

Very young seedlings of crested wheatgrass present a very difficult problem in identification. There are a few characters, however, that appear to be reliable for identification during the first 31 days after planting, or until there is a definite formation of the vegetative characters similar to those of the mature plant.

At the end of 10 days after planting, the number of veins in the first leaf was almost always three. The coleoptile was often greenish pink in color. The first leaf was about 0.75 mm wide, green, curled,

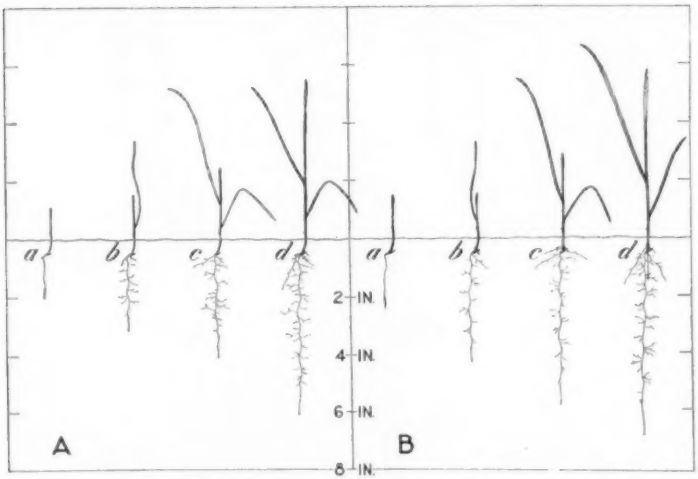


FIGURE 4.—Comparison of the development of root and shoot of crested wheatgrass (A) and bromegrass (B): *a*, 10 days after planting; *b*, 17 days after planting; *c*, 24 days after planting; *d*, 31 days after planting

and somewhat convolute. At the end of 17 days after planting, the first leaf still had three veins and was about 1 mm wide. There were a few hairs along the veins. Twenty-four days after planting, the first leaf had the same characteristics as those mentioned above, except that sometimes there appeared to be a slight development of auricles. The second leaf had five veins, was green, and about 1.25 mm wide. There were several hairs along the veins. The ligule, collar, and sheath resembled those of the mature plant and the auricles were slightly developed. The third leaf was light green, convolute, 1 mm wide, and had from three to five veins. There were a few hairs along the veins. Thirty-one days after planting, the coleoptile began to slough off. The first leaf had not changed and the second leaf had changed but slightly. The latter was 1.5 mm wide and the auricles were much more pronounced. The third leaf was green and about 2 mm wide. It had about six veins and several hairs along the veins.

Ten-day-old seedlings of crested wheatgrass may be distinguished from those of bromegrass by the width of the leaf, the number of veins, and the hairiness. From the seventeenth day after planting crested wheatgrass may be distinguished by the characteristic ligule, collar, and auricles.

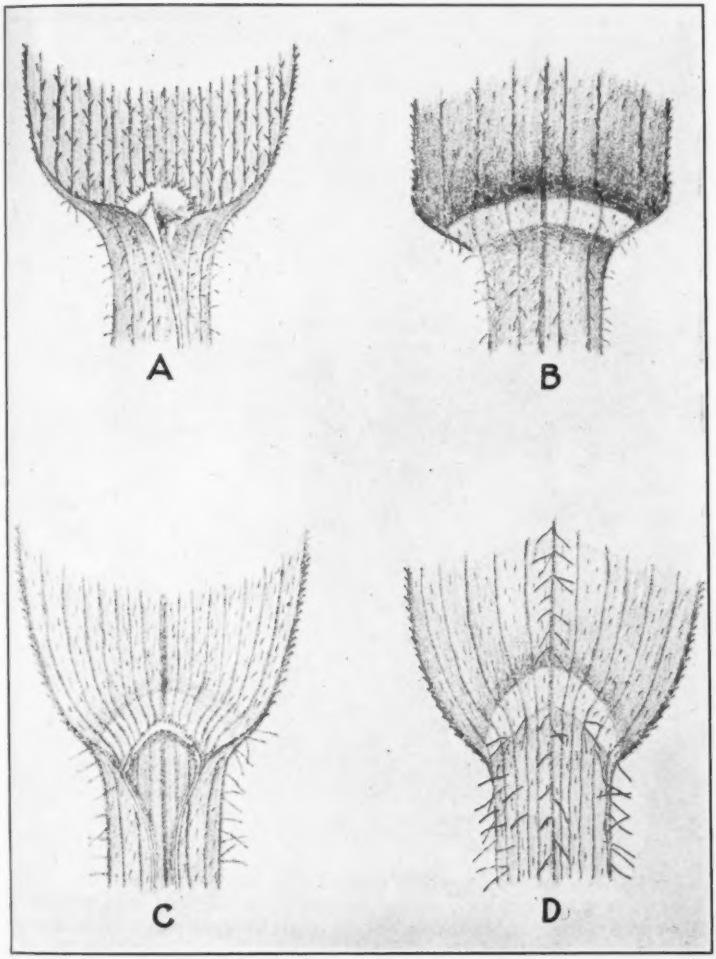


FIGURE 5.—Base of mature blades, showing sheath, collar, and ligule of crested wheatgrass (A, B) and bromegrass (C, D)

## DEVELOPMENT AND MORPHOLOGY OF THE MATURE PLANT

Crested wheatgrass is a perennial of bunch-grass habit; 20 to 30 inches high; leaves rolled in the bud; collar broad, somewhat hairy; auricles slender, clawlike; ligule membranaceous, short, much lacerated; sheath not compressed, somewhat hairy; blades flat to convo-

lute, usually stout hairs along the veins, 0.12 to 0.25 inch wide, somewhat tapering to a slender, sharp point; nerves prominent on upper surface. (Fig. 5.)

From one and one-half to two months after planting, crested wheat grass begins to tiller. New stalks arise from buds on the basal node. The crown increases in size in this manner, very often exceeding several square inches in area. From nodes on old tillers or secondary stems, new groups of tillers arise, as shown in Figure 6.

In the spring, the new growth begins both from the base of old stalks and from new buds arising at nodes. Very often these new

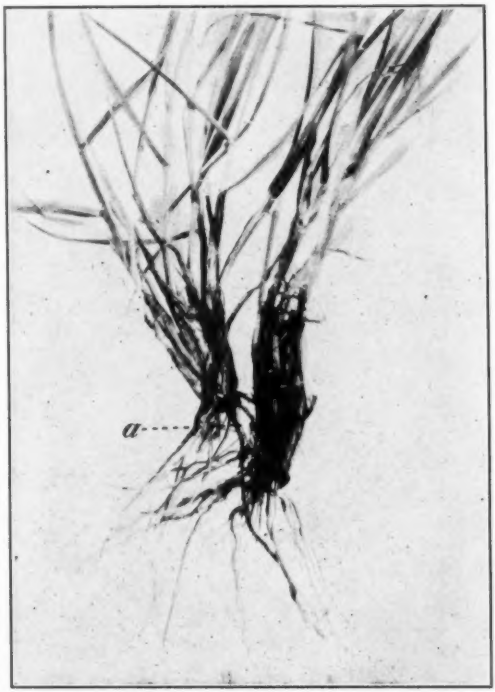


FIGURE 6.—Method by which clumps of crested wheatgrass enlarge. Note tillering from the secondary stem (*a*) and also from the primary stem below

shoots appear above the surface several inches away from the crown. The culms are erect and under favorable conditions will produce a spike, but under unfavorable conditions the apex ends in a mass of false leaves.

In the latter part of October, 1930, the root systems of crested wheatgrass and bromegrass were excavated by the trench method. Both plots in which plants were growing had been seeded in the spring of 1929 by the Department of Agronomy of the North Dakota station. The soil is Fargo clay [4] (alkali phase) and includes three

[4] KNOBEL, E. W., PEIGHTAL, M. F., and CHAPMAN, J. E., SOIL SURVEY OF CASS COUNTY, NORTH DAKOTA. HOPPER, T. H., and WALSTER, H. L. PART 2: THE CHEMICAL COMPOSITION OF THE SOILS OF CASS COUNTY, U. S. Dept. Agr., Bur. Chem. and Soils, Soil Survey Rpt. No. 29, Series 1924, 80 p., illus. [1929.]

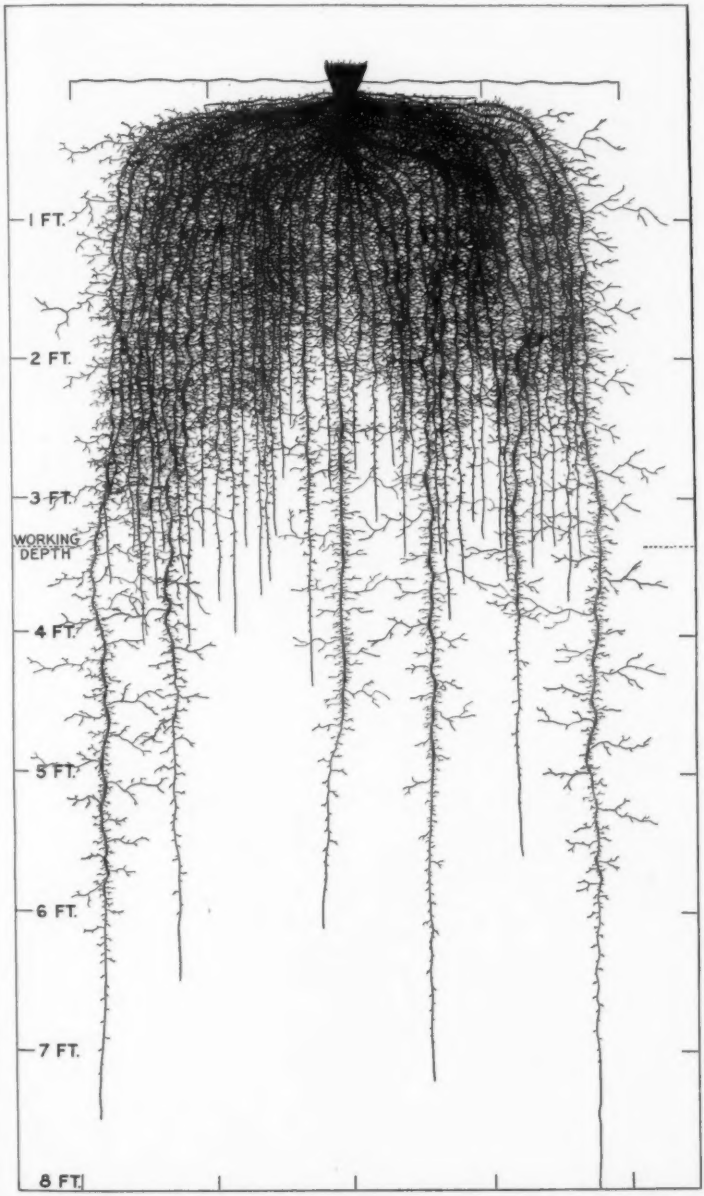


FIGURE 7.—Root system of crested wheatgrass at the end of the second season, one-fourth of the total roots being shown. Fargo, N. Dak,. October, 1930

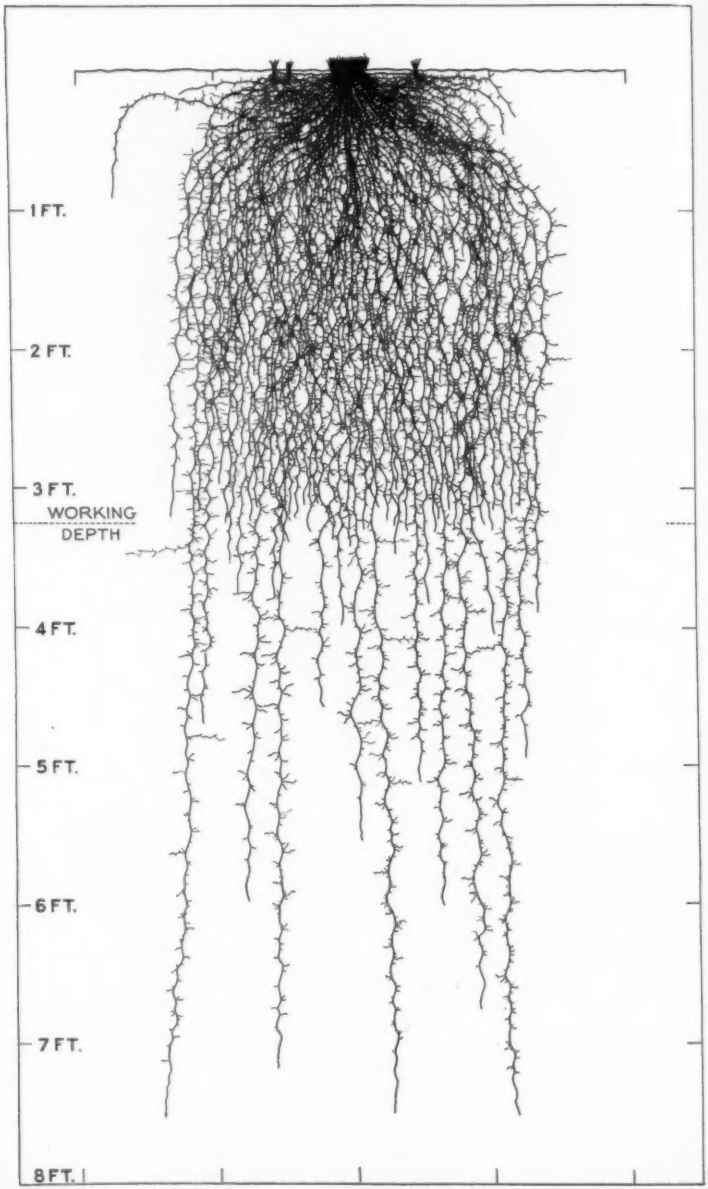


FIGURE 8.—Root system of bromegrass at the end of the second season, one-fourth of the total roots being shown. Fargo, N. Dak., October, 1930

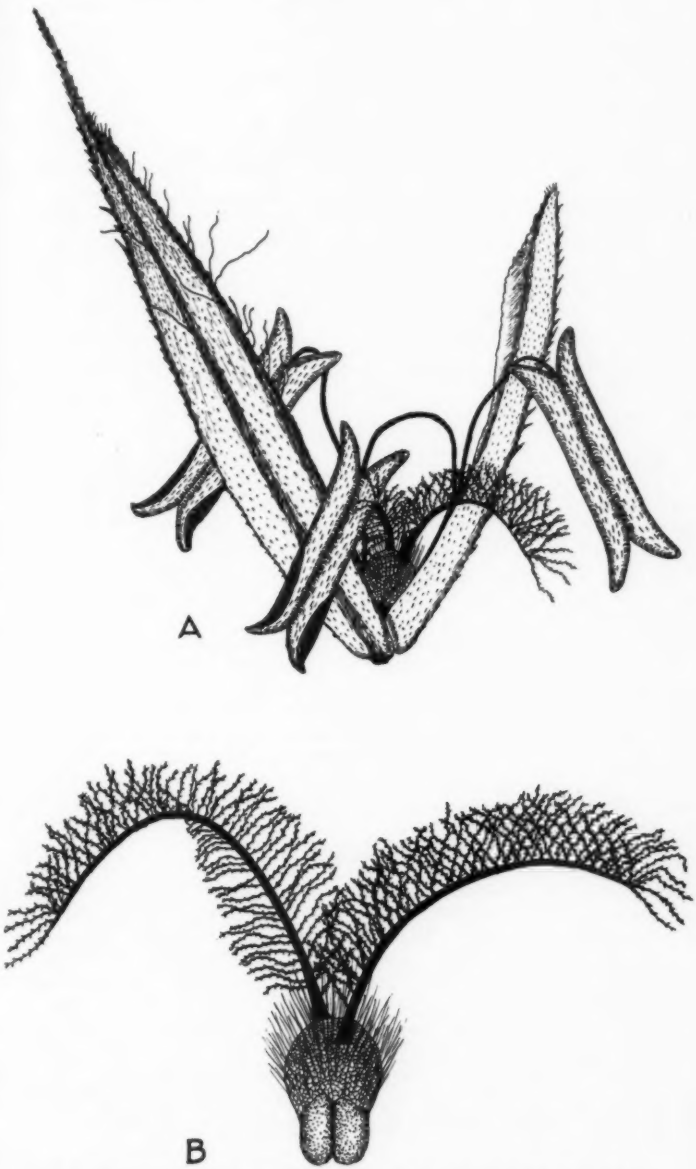


FIGURE 9.—Floret (A) of crested wheatgrass, with an enlarged style and ovary (B)

distinct horizons. The A horizon consists of a black clay to a depth of 19 inches; the B horizon is composed of a grayish-drab or olive-gray clay, containing scattered concretions of lime carbonate, and extends to a depth of 32 inches; the C horizon consists of an olive-gray or light olive-gray clay to a depth greater than 8 feet.

Crested wheatgrass (fig. 7) penetrated to a maximum depth of 8 feet, with a lateral spread from the crown of a little over 2 feet. A majority of the roots extended to a depth of 3.3 feet (working level). The root system as a whole was in excellent condition. The main roots ranged from 0.4 to 1.5 mm in diameter. The light-colored main roots, arising from 1 to 2 inches below the soil surface gave rise to numerous secondary and tertiary rootlets from near the surface to within 3 inches of the tip. The ratio of the maximum depth to the lateral spread was 3.6. The lime carbonate in the B horizon. appeared to have little effect on the color or growth of the main roots,

Bromegrass (fig. 8) penetrated to a maximum depth of 7.5 feet with a lateral spread of a little over 1.5 feet. A large number of the roots extended to the working depth of 3.2 feet. The main roots. arising directly beneath the soil surface, were pale straw-colored in the A horizon and dark brown in the B and C horizons. Several roots, after striking the B horizon, grew horizontally for about 1 inch and then turned downward. Many secondary rootlets were swollen to about twice normal size at the tips between depths of 2 to 4 feet.

A few dead roots were found, some extending to a depth of 3 feet. Where the lime carbonate deposits were shallower, the working depth was found to be 3 feet. The ratio of the maximum depth to the lateral spread was 5.0.

The root systems of crested wheatgrass and bromegrass are similar in that they penetrate to about the same depth and have about the same working level. On the whole, the main roots of crested wheatgrass are lighter in color and somewhat stouter. Crested wheatgrass has a much greater number of branch roots than bromegrass and they are not so coarse as those of brome. The absorbing surface of crested wheatgrass appears to be much greater than that of bromegrass. The lateral spread of the roots of crested wheatgrass is greater than that of brome.

## INFLORESCENCE

The spikes of crested wheatgrass begin to develop from two to three months after the plant commences growth in the spring. At the time of blooming the style appears shortly before the stamens are mature and the anther sacs have broken. In Figure 9 is shown a floret shortly after the anther sacs have opened. An enlargement of the styles and ovary is also shown. The lodicules are quite large and are just beneath the base of the ovary. The long hairs on the ovary are conspicuous. Both the lemma and palea are provided with numerous short, stout hairs. On both sides the lemma has one distinct nerve down the middle, parallel with the two outside nerves. Several long hairs are seen at various points on the lemma.

SUMMARY

The seed of crested wheatgrass may be distinguished from the seeds of *Agropyron repens*, *A. smithii* and *A. tenerum* by its rolled lemma and palea, its wide blunt base, and the characteristic oblong shape of the apex of the rachilla segment.

Crested wheatgrass seed when stored in a cool, dry place may be expected to retain its viability with but little deterioration for four years.

Experiments on the depth at which crested wheatgrass seed should be planted show that the optimum is from one-fourth to one-half inch, varying with the dryness of the surface soil.

Crested wheatgrass seedlings grow much more slowly during the first 24 days than bromegrass seedlings. From that time on crested wheatgrass seedlings develop just as rapidly, or even more rapidly, than bromegrass seedlings.

Very young seedlings of crested wheatgrass may be distinguished by a number of characters such as the greenish-pink color of the coleoptile, the three veins in the first leaf, and slenderness of the entire plant.

The method by which the crowns of crested wheatgrass enlarge is described.

The root system of crested wheatgrass at the end of the second season extended to a depth of 8 feet, with a lateral spread from the crown of a little over 2 feet. The working level was about 3.3 feet. The entire system had very many fine secondary and tertiary branches.

The flower is described. The styles appear before the stamens are mature.

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